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OF THE
SCIENTIFIC LABORATORIES
OF
DENISON UNIVERSITY

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The entire file of volumes 1 to 13 was destroyed by fire; no publications issued prior to 1907 are now available. Volumes 14 to date may be obtained from the editor at $2.00 per volume, with the exception of volume 15, the price of which is $1.00. Separate parts, as listed below, may be purchased at the prices indicated.

FOREWORD

The Bulletin of the Scientific Laboratories was established in 1885 by C. L. Herrick, who at that time filled the chair of "Geology and Natural History" at Denison. Two years later it became the official organ of the Denison Scientific Association, and has since been edited by the "Permanent Secretary" of that organization, a position occupied by various members of the science staff. The funds to support the publication have been provided by the Trustees of Denison in recognition of the fact that it is the province of the University not only to dispense information, but to enrich the store of human knowledge by original research and independent investigation. The pages of The Bulletin are open to contributions from the members and past-members of the Denison Scientific Association; articles submitted for publication will be welcomed by the editor at any time.

It is appropriate in this connection to acknowledge the indebtedness of the University and the Scientific Association to Dr. Frank Carney, formerly Professor of Geology, who was editor of The Bulletin from 1908 to 1917. Volumes 14 to 18, inclusive, were issued under his direction; they include more than half the total number of pages published since 1885. His editorial ability and facile pen did much to establish The Bulletin on a high plane of scientific excellence and to bring it the recognition in the realm of science, both in America and abroad, which it now enjoys.

Clark W. Chamberlain.

ECHINODERMATA OF THE BRASSFIELD (SILURIAN) FORMATION OF OHIO

AUG. F. FOERSTE

Relatively few echinoderms from the Upper or Albion division of the Medinan Silurian have hitherto been described. From the Cataract strata of Ontario, *Brockocystis clintonensis* (Parks), *Brockocystis huronensis* (Billings), *Brockocystis tecumseth* (Billings), *Mesopalaeaster* (?) *cataractensis* Schuchert, and *Mesopalaeaster granti* (Spencer) are known. From the Girardeau of Missouri and Illinois, *Cyclocystoides illinoisensis* Miller and Gurley, *Glyptocrinus* (?) *fimbriatus* Shumard, and *Ptychocrinus splendens* (Miller) have been described. *Deltacrinus alleni* (Rowley), *Gissocrinus* (?) *problematicus* Rowley, *Glyptocrinus inseparatus,* with its varieties *carinatus* and *pentagonus,* all by Rowley, have been described from the Edgewood of Missouri and Illinois.

Although the Brassfield formation of Ohio, Indiana, and Kentucky contains almost everywhere a considerable quantit of coarsely crinoidal material, only one species, *Clidochirus americanus* Springer, has been listed by Bassler from this formation; even this species, so far, has not been published.

This extreme poverty of echinoderm material from the Brassfield formation may be easily understood on studying the lithology of the rock. Where the echinoderm material is most abundant the rock gives evidence of having been deposited by strong and irregular currents. Cross-bedding is common. The fragmental material is more or less rounded. Dismembered plates and columnals of crinoids are common, fragments of columns an inch or more in length are not infrequent, but rarely are enough plates of the same calyx still found in their original relative position to make possible even a generic identification. The material described on the following pages represents all

the writer ever found which is worthy of any attention. A close discrimination of the calyx plates and of the fragments of columns suggests that the Brassfield sea contained an abundance of crinoidal life, representing many species. The trouble is not with the lack of abundance, but with the dismembered condition of this material.

Under the term crinoidal material, fragments of cystids frequently are included. Pectinirhombs, such as exist among the Glyptocystidae, occur in considerable numbers at some localities. Starfish material is extremely rare. In a dismembered condition it probably could not be recognized as such.

Fragments of calyces with a number of plates still in position occur occasionally in the soft blue clay forming the top of the Brassfield formation at the quarry northwest of the railroad station at Centerville, and at the equivalent horizon in the abandoned quarry at the Soldiers Home, west of Dayton, Ohio. In the area southeast of Byron, about 8 miles northwest of Xenia, Ohio, the weathered top of the Brassfield limestone not infrequently retains the basal portions of crinoid calyces, but usually poorly preserved. Unfortunately the exposed rock surface is relatively small; otherwise this area might give promise of more crinoid material.

In the southern part of Ohio, in Highland and Adams counties, *Brockocystis nodosarius* is represented by numerous fragments in the lower third of the Brassfield formation; fairly preserved thecae, however, were found only at one locality, about two miles west of Peebles. Two of the starfish described from this part of the state, on the following pages, were obtained near the top of this *Brockocystis* zone.

In addition to the material from the Brassfield, there is described on the following pages *Clidochirus ulrichi*, the only crinoid found so far in the Dayton limestone. This limestone lies immediately above the Brassfield formation and is correlated with the *Pentamerus* limestone in the lower part of the Clinton formation of New York. A poorly preserved specimen of *Botryocrinus*, from the *Holophragma* zone at the top of the Upper or Lilley member of the West Union formation at Hillsboro.

Ohio, also has been added. This upper member of the West Union formation is distinct faunally from the Lower or Bisher member. The latter is correlated provisionally with the Irondequoit member of the Clinton of New York, so that the upper member may correspond to the lower part of the Lockport formation of that state. The so-called Niagara shales of the earlier reports of the Ohio Geological Survey, known as the Crab Orchard shales in Kentucky, contain, in their upper layers, a fauna including some of the characteristic species of the typical Clinton of the central and more eastern parts of New York, such as *Liocalymene clintoni.*

Several of the specimens here discussed present very unusual features. The nodose aggregation of columnals at the top of the stem of *Brockocystis nodosarius* is one of these. The frequent coiling of the stem of an unknown crinoid, (plate I, fig. 6), with the narrow end of the stem at the center, is another. An ancestral form of *Myelodactylus* is a third. On plate II (fig. 6) are figured fragments of a crinoid which would be a *Dimerocrinid* if it had sub-basal plates; but the latter apparently do not occur. On plate VII are presented several figures of an echinoderm (*Stereoaster*) regarding which little is known at present beyond the fact that it resembles a star-fish in appearance but not in structure. It promises to be one of the anomalous forms of which the relationship remains unknown, at least for the present. Finally, on plates IV and V is figured a star-fish which evidently diverges distinctly from typical forms of *Mesopalaeaster.*

Brockocystis nodosarius sp. nov.

Plate I, figs. 1, 2, 3, 4, 5

Theca small, oblong in outline, 11 or 12 mm. long and 9 or 10 mm. wide. Pectinirhombs present on plates 1–5, 12–18, 14–15, and 10–15, but absent on plates 11–17; more or less discrete along the suture which separates the two plates forming each rhomb. The lower boundary of the pectinirhombs is more strongly defined on plates 1 and 12 than is the corresponding upper boundary of the same pectinirhombs on plates 5 and 18.

The number of stereom-folds in pectinirhomb 1–5 is 3 or 4; in pectinirhomb 12–18, about 5 or 6; in pectinirhomb 14–15, about 7 or 8; and in pectinirhomb 10–15, about 4 or 5.

Prominent protuberances occupy the middle of all the plates belonging to the first three rows. The protuberances of the four basal plates project downward, beyond the top of the column, for distances approaching or equalling one millimeter. Where pectinirhombs are present, the latter encroach on the central protuberances, and similar encroachment is noticed also in case of the plates bordering on the anal area; the encroachment is least in case of plate 7. In some specimens, low ridges connect the protuberances of adjacent plates; in others they are absent. In their present state of preservation the plates appear smooth. Anal area apparently elliptical in form, about 3 mm. in height and 2 mm. in width. None of the plates belonging to this area are preserved in the specimens at hand.

Only traces of the food-groove system remain. The ambulacra recline on the surface of the theca as in other *Lepadocystinae.* In one specimen, one of the ambulacra passes along the upper left margin of plate 17 to within one millimeter of the top angle of plate 11; another ambulacrum reaches the upper part of plate 18, but does not extend nearer than one millimeter to the upper margin of that part of the pectinirhomb which is present on this plate. In the same manner, ambulacra reach only the top of plates 19 and 15. This is true presumably also in case of plate 16, although this plate is not exposed in any specimen at hand. There scarcely is room for more than two or three brachioles on each side of each ambulacrum. These brachioles are at least 5 mm. long, and are directed upward. They are biserial dorsally, the plates of the two series alternating. The length of these dorsal plates equals or only slightly exceeds their width. The ventral side of the brachioles is not exposed in any specimen at hand but its probable appearance may be inferred from the corresponding parts of *Lepadocystis moorei,* Meek, a closely related species occurring in the upper part of the Richmond group, at Richmond, Indiana. In the latter species the covering plates on the brachioles are more numerous than the dorsal plates; in

outline they are long and linear, with their longer axes directed at right angles to the length of the brachiole. The ambulacral plates which remain attached to the theca of the species of *Brockocystis* here under discussion appear to be of comparatively large size and are relatively few in number.

The semilunate pore (gonopore) on plate 23 is distinct y defined in the angle between the two ambulacra which extend toward plates 17 and 18. A more minute pore (hydropore) may be present directly beneath the center of the semilunate pore, but is not distinctly defined. Plate 23 may be a double plate; at least, a crack appears to pass through the center of the semilunate pore.

The largest fragment of a column remaining attached to any theca known is 20 mm. in length. In the more distal parts of the column, for a length of 12 mm., the column is narrow, ranging from two-thirds to a whole millimeter in width, the proximal columnals being broader. In the prox'mal part of the column, 8 mm. in length, the columnals are collected into two groups, of which the first is inversely pyriform, and the second is inversely truncate-conical in form. The constituent columnals of each group are anchylosed together, but the groups separate readily from each other and from the remainder of the column. In this separated condition the groups form characteristic fossil remains easily identifiable generically, even in the absence of the theca. This is true especially of the inversely pyriform groups. A vertical section of one of these groups (fig. 5) shows a lumen from three-fourths of a millimeter to a whole millimeter in width. Along this lumen, the constrictions locating the inner parts of the columnals appear equally spaced, six columnals occupying a length of slightly more than 3 mm. Exteriorly, the marginal parts of the constituent columnals of the inversely pyriform groups rise, so that externally the lower three or four columnals of each group appear distinctly longer than the upper three or four columnals of the same group. The topmost columnal is constricted in size to the width of the lowest columnal, and is hidden in the base of the large depression indenting the top of the group. To this hidden columnal is attached the second

group of columnals, of which six columnals occupy a length of about 2.3 mm. This second group also has a deep, wide depression at the top, as though the inner part of the body-cavity of the tegmen were connected directly with the lumen. The upper margin of this second group is overlapped by the descending extensions of the protuberances on the basal plates of the theca. If the proximal columnals are the youngest, then the second group may be due merely to a rejuvenation of the process which gave rise to the first group. When the upper margin of the first group had attained such a size that it crowded upon the overlapping extensions of the basal thecal plates, a new series of smaller columnal plates appears to have been started. It is conceivable that stereom was added to the exterior of the columnals after the more central parts already had been formed.

In the figured specimens, the surface of the thecal plates appears to be smooth; however, on many of the loose thecal plates, evidently belonging to the same genus, the surface of the plates is covered by a reticulated series of lines, similar to that shown by *Brockocystis tecumsethi* (Billings) (plate III, fig. 1) from the top of the Manitoulin dolomite, on Manitoulin island, in Ontario, Canada. It is possible that there are two species of *Brockocystis* in the Brassfield strata of Ohio, but if that be true, this fact has not yet been definitely determined.

Locality and position. The specimens here figured were obtained in the lower part of the Brassfield formation, beneath a trestle along the railroad about two miles west of Peebles, Ohio. They were in the upper part of the cherty layers which occur a short distance above the base of the Brassfield formation in the southern part of the state. The following section is exposed beneath the trestle, in descending order:

	feet.
Limestone, cherty nodules few	3
Limestone, in more massive beds, cherty nodules large and numerous	3
Limestone, thinner bedded, cherty nodules small and few	2
Limestone, thin-bedded, no chert noticed	2.5
Creek level beneath tressle.	

The following fossils were secured here, chiefly from the upper half of strata here listed, which belong to the more cherty part

of the section: *Cyathophyllum facetum, Brockocystis nodosarius, Hemitrypa ulrichi, Phaenopora multifida, Rhinopora verrucosa, Hebertella daytonensis, Hebertella fausta, Orthis flabellites, Platystrophia daytonensis, Leptaena rhomboidalis, Plectambonites transversalis, Strophonella daytonensis, Illaenus ambiguus,* and *Phacops pulchellus.*

At the quarry directly north of Lawshe, Ohio, the strata equivalent to the cherty limestones listed above are underlaid by several thinner bedded limestone layers containing *Platymerella manniensis* Foerste (Bull. Sci. Lab. Denison Univ., vol. 14, 1909, p. 70, pl. 1, figs. 1 A–D) and *Plectambonites transversalis.* So far, this is the only locality known in Ohio, Indiana, or Kentucky, at which *Platymerella* occurs.

The geographical range of *Brockocystis nodosarius* is limited to the southern part of Ohio. No specimens have been found so far in the neighboring parts of Kentucky. It occurs at numerous localities in Adams and Highland counties, in Ohio, and has been found also at Sharpsville, in the southern angle of Clinton county. The most western locality at which it has been noted is the quarry in the creek bottom, a short distance east of Danville. Eastward, its range appears limited only by the extent of the outcrops.

An unknown Brassfield Lepadocystid

Plate II, fig. 2

Detached plates of some Lepadocystid are common within 5 feet of the top of the Brassfield formation at the exposure along the electric railroad where it follows the Dayton and Troy pike, about a mile northwest of Cowlesville, in the southern part of Miami County. Many of these plates bear pectinirhombs, and occasionally one of them bears the double pectinirhomb characteristic of plate 15 in the genera *Brockocystis* and *Lepadocystis.* In some of the plates the halves of the pectinirhombs are broad but of small height; they lie near the margin of the plates; the inner margin of the pectinirhomb is gently concave, the outer margin consists of two sides meeting at a very obtuse angle at

the middle; both the outer and inner margins are delimited by a narrow linear elevation. On other plates the halves of the pectinirhombs lie farther from the margins of the plates, and the outer margin as well as the inner margin of the pectinirhomb is more lunate in outline. There is no evidence of central nodose elevations on any of these plates, nor of any prominent radiating sculpture.

The associated columns are circular in cross-section, with a circular lumen. The columnals are of very short height, 15 occurring in a length of 5 mm. in a column 6 mm. in diameter. The ends of these columnals are finely and radiately striated. There is no tendency toward the grouping of these columnals into more or less nodose or pyriform sections.

Both the dissociated plates and the associated columns probably belong to some undescribed species from among the Lepadocystinae, possibly to *Brockocystis*.

Similar plates and columns occur at the same horizon at various localities in the southern part of Miami and Clark counties and in the northern halves of Miami and Greene counties. No attempt has been made to determine their area of distribution. They are described here chiefly to call attention to the presence of additional cystids in the Brassfield formation in the hope that more perfect specimens may be found.

Coiled "crinoid" stem

Plate I, fig. 6; plate II, figs. 5 A-C

1884, American Naturalist, p. 57

A coiled column of some echinoderm, obtained in the upper part of the Brassfield limestone in the Soldiers Home quarry, west of Dayton, Ohio, was figured by the writer thirty-five years ago. This column was at least 11.5 cm. long, but, on the supposition that almost all of the second largest volution is missing, an original length of at least 21 cm. is probable. This column increased from a diameter of 1.5 mm., at the smaller end of the column, to a diameter of 6.5 mm. in a length of 7.7 cm. Beyond

this point, the volutions were not preserved continuously. The columnals were approximately circular, with a moderately irregular margin.

A second coiled column, (plate I, fig. 6) evidently belonging to the same species, was found recently, also in the upper part of the Brassfield limestone, 1 mile northeast of Wilberforce, and 4½ miles northeast of Xenia, Ohio. The exposure occurs east of the road to Clifton, on the northern side of the road to the Eastpoint school, along the upper part of the creek bed. Here large dissociated columnals of the same species are very common in the ferruginous layer, 2½ feet below the base of the Dayton limestone. The coiled column found here has a length of 16.4 cm. About three and a third volutions are preserved. Measuring from the larger toward the smaller end, the first volution has a length of 9.1 cm.; the second, of 5 cm.; the third, of 1.8 cm.; and the remainder, of 0.5 cm. At the larger extremity the columnals have a diameter of 8 mm.; at a distance of 7.8 cm. from the larger end this diameter is 6.5 mm.; 7.7 cm. from the second point the diameter equals 2.7 mm.; at its smallest extremity the diameter is only slightly more than 1.5 mm. These measurements suggest that the rate of decrease in the diameter of the column is more rapid nearer the smaller extremity. The margins of the columnals are badly weather worn but apparently were approximately circular, with a moderately irregular margin.

The columnals are not of equal thickness. This is more readily noticeable in the larger columnals. Frequently narrower and thinner columnals alternate with thicker ones in such a manner as to suggest intercalation subsequent to the development of the larger columnals. This is a familiar feature among various genera of crinoids. Since both the larger and the intercalated smaller columnals become thinner toward the lumen, it is evident that articulation is secured by still smaller columnals, not readily seen in a view of the exterior of the complete column, though frequently still attached to the disarticulated larger columnals. The articulating surface of these articulating columnals, and the corresponding surface of that part of the larger columnals which surrounds the lumen, is radiately striated.

Similar coiled crinoid stems, evidently belonging to the same species, have been found recently also at the large quarry northwest of the railroad station, at Centreville, Ohio.

Disjointed columnals (plate II, figs. 5 A–C) are very common near the top of the Brassfield limestone, both in Ohio and in eastern Kentucky. The maximum size attained by these columnals is 25 mm. Most of them do not exceed 15 mm. in width. Columnals between 15 and 25 mm. in width usually are almost circular in outline with little evidence of crenulation. Smaller columnals frequently are crenulated; some of the smaller specimens are pentagonally lobed; when they are both lobed and crenulate they frequently are very pretty and attract attention as beads. In both of the coiled columns found so far the outlines of the columnals are moderately crenulated but not pentagonal in outline. Whether the more or less pentagonal columnals represent a different species is unknown at present. On many of these columnals it is possible to recognize five equally distant, radiating, narrow color lines suggesting former sutures, and indicating the pentamerid origin of the columnals.

The radiating striae on the articulating surface of the articulating columnals, described above, number 10 or 11 in a distance of 1 mm. They correspond closely in appearance with the striae on the articulating surfaces at the base of the calyces of the two species of crinoids described next. Both of these species occur at the top of the Brassfield formation in the area southeast of Byron, about 7 miles northwest of Xenia, Ohio. Both are found at about the same horizon as the coiled stem described from the top of the Brassfield limestone, 1 mile northeast of Wilberforce. Both are very similar in the size and the outline of the first three circles of plates, and apparently even in the degree of development of the very low but broad radiating ridges ornamenting the plates. They differ chiefly, as far as the calyces are known at present, in the shape of one of the plates in the first or basal circle. In the first species here described, (plate II, figs. 6 A–E) the top of one of the basal plates is truncated, indicating the position of the anal side of the calyx. In the second species all of the plates belonging to the first circle

are pentagonal in form, and there is no indication of the anal side in the part of the calyx known at present. Moreover, in the second species, (plate VI, figs. 2 A–D) the surface ornamentation consists of numerous parallel lines which are perpendicular to the adjacent sides. The surface of the first species appears to have been relatively smooth.

At present there is no means of determining whether the coiled crinoid stems described here belong to either of these two species, but the latter are the only forms known of such size as to suggest the possibility of such a relationship.

Dimerocrinus (?) **vagans** sp. nov.

Plate II, figs. 6 A–E

Basals five, four of them pentagonal in outline, the fifth truncated and supporting the anal x plate. The inner margin of the circle of five basals is formed by the aperture connecting the lumen of the stem with the body-cavity of the calyx. The articulating surface for the attachment of the column is formed by a circular ridge which encloses the proximal parts of the five basals. The area thus enclosed is deeply concave. The crest of the circular ridge traversing the basals is marked by numerous, very fine, short lines arranged as though radiating from the center of the circle. About 9 or 10 of these lines occur in a width of 1 mm. No infrabasals are present in any of the specimens found. In the specimen represented by figure 6A the margin of the articulating surface appears to be slightly scallopped, somewhat as in figure 6D. If this could be confirmed by well preserved specimens it would indicate the former presence of infrabasals. The presence of such infrabasals would relegate our specimens to the Dimerocrinidae. As a matter of fact, however, the former presence of infrabasals remains extremely doubtful, in which case the calyces here described would not fit into any of the families of Crinoidea as now defined. Figure 6D is intended to indicate the possible relationship of these calyces to the Dimerocrinidae.

Judging from the fragments at hand, the basal part of the calyx must have been comparatively flat as far outward as the distal parts of the first interradials. Beyond the latter, the sides of the calyx probably curved more or less rapidly upward, producing a semi-globose form, flattened beneath, possibly similar to that of *Lyriocrinus*. The lateral diameter of the calyx must have equalled at least 60 mm. Obscure lines of elevation traverse the plates somewhat as indicated in figure 6E.

Locality and position. Within 2½ feet from the top of the Brassfield limestone, 7 miles northwest of Xenia, Ohio. The locality may be reached by going 1 mile east from Byron, then 1 mile south, to a shallow wet-weather stream exposure, on the east side of the pike.

Base of calyx of unknown species of crinoid

Plate VI, figs. 2 A–D

At the same locality and horizon as the preceding species, southeast of Byron, Ohio, occur the basal parts of the calyces of a second species of crinoid, closely resembling the preceding species in general appearance. The chief difference consists in the fact that there is no differentiation of the anal side among the basals, nor, apparently, among the radials and first interradials, as far as the latter are preserved. All of the basals are pentagonal in outline. The articulating surface for the attachment of the column is similar to that of the preceding species. If infrabasals ever were present, this fact remains to be proved. The plates of the calyx are ornamented by close-set parallel striae arranged in groups which are perpendicular to the adjacent suture lines. In intermediate parts of the plates these striae tend to break up into series of granules which are elongated more or less in the direction of the neighboring striae. The general form of the calyx probably was similar to that of *Lyriocrinus melissa* Hall.

This second species appears so closely similar to the preceding species here described, as far as preserved, that there is a possibility of both belonging to the same family of crinoids. All the Dimero-

crinidae, however, have an anal plate following a truncated basal. In the present state of our knowledge of these calyces any attempt to assign them to some definite family of crinoids would be merely guesswork. The chief reason for calling attention to them is the fact that this and the preceding species possibly may belong to the interesting coiled crinoid stems described earlier in this paper. They are of sufficient size, have a large enough lumen, the surface markings on the area of attachment are similar, the specimens occur at the same horizon, and in sufficient numbers at least to suggest a possible former connection.

Figure 41 on plate VIII of vol. 3, Bull. Sci. Lab. Denison University, probably represents another specimen of the same species as that here described. This figure is reprinted on plate 27 of vol. 7 of the Ohio Geological Survey, published in 1895. The specimen was obtained at Reed's hill, east of Fairfield, Ohio.

Clidochirus sp.

Plate VII, fig. 1

Species named by Springer in his Monograph of the Crinoidea Flexibilia, now in press.

Infrabasals low, not exceeding 1 mm. in height, presumably three although the complete circuit is not preserved in the specimen at hand; exposed surface erect, taking part in the calyx wall and having about the same slope as that of the basals. The right posterior infrabasal is broadly triangulate above. The anterior and right anterior infrabasals are merged into a single plate with a gently concave upper surface, bearing the right anterior basal. Although the left anterior and left posterior basals are only imperfectly preserved, it is assumed that these plates also are merged into a single plate with a gently concave upper margin, bearing the left posterior basal. The height of the basals only slightly exceeds their width, excepting in the case of the posterior basal which is a little higher and bears the anal x plate on its upper right margin. This anal x plate is in contact with the upper left margin of the radial at the base of

the right posterior arm, and also with the left side of the first costal and the lower left side of the second costal belonging to the same arm; on the other side, this anal x plate is in contact with the right side of the radial and the lower right side of the first costal belonging to the left posterior arm. Each arm begins with the radial followed by two costals, except in the case of the right posterior arm where the presence of the "radianal in its primitive position under the right posterior radial, resting on the basals" (Springer) produces the appearance of a radial followed by three costals. The distichals in each arm-branch number four, excepting in the case of the left branch of the left posterior arm, where only three distichals occur. Most of the subsequent branches expose six palmars, but the tips are infolded and are not well exposed so that the number of palmars may equal seven or eight, or even may exceed that number. The arms all are closely adjoined laterally.

Locality and position. In the clayey layers at the top of the Brassfield formation, in the large quarry half a mile northeast of the village of Centerville, Ohio.

Remarks. This species is characterized by its elongate form. The sides of the calyx diverge at an angle of about 40 degrees as far as the axillary costals. The series of distichals are more nearly vertical, and, beyond the distichals, the series of palmars are incurved. The ratio of the length to the width of the entire crown is about 17 to 10.

Figure 39 on plate 8, vol. 3, Bull. Sci. Lab. Denison University, republished on plate 27 of vol. 7 of the Ohio Geological Survey in 1895, represents a specimen obtained in the soft clay at the top of the Brassfield formation, at the Centerville quarry. In the original publication it was described as *Ichthyocrinus sp.;* a fragment of the calyx. This reference to *Ichthyocrinus* is based solely upon the close lateral abutting of the arms, and the general aspect of the fragment. At the base of the fragment is an axillary costal, followed by two arm-branches, each with three distichals; this is followed by four arm-branches, the two median ones with five palmars, the right-hand branch with eleven palmars; beyond the palmars, branching takes place

again. A part of another arm forms the right side of the fragment; the distichals of the left branch are followed by two arm branches, of which the left one has nine palmars, and the right one has five palmars. In the case of each arm, the two median arm branches following the distichals are broader and shorter; the two exterior arm branches of the same set are narrower and longer, recalling in this respect *Clidochirus* of which it may be another species.

Clidochirus ulrichi sp. nov.

Plate II, figs. 1 A, B; text figure 1

Infrabasals three, 1.3 mm. in height, exposed surface sloping at the same angle as the basals. Basals, 2.5 mm. in height. Radials, except in the case of the right posterior arm, 2 mm. in height. Radials, except in the case of the right posterior arm, followed by two costals, of which the first has a height of 1.7 mm. while the second or axillary costal has a height of about 2 mm. at its middle. The right posterior arm appears to consist of a radial followed by three costals, and the designations first, second, and third or axillary costal are used in connection with this arm in the immediately following parts of this description. The radianal is relatively long and narrow, narrowing especially toward the base; it lines the left margin of the radial at the base of the right posterior arm for its entire length and borders also on the lower left margin of the first costal of this arm. The anal x plate borders on the lower left margin of the second costal and lines the left margin of the first costal of the right posterior arm; on its left side it barely reaches the lower right corner of the second or axillary costal, but borders on the right side of both the first costal and the radial. In all arms there are four distichals in each vertical series. Each arm terminates with four series of palmars, of which, in the specimen at hand, the two outer series consist of about eleven or twelve palmars, while the two inner series appear to be shorter and to consist of only eight or nine palmars.

Column slender, about 1.8 mm. in width. Columnals varying between 0.4 and 0.5 mm. in length, frequently alternating with much shorter intercalated columnals.

Locality and position. In the upper part of the Dayton limestone, at the base of the Niagaran division of the Silurian, along the side of the Germantown pike, southeast of the Soldiers Home, west of Dayton, Ohio. Named in honor of E. O. Ulrich, whose

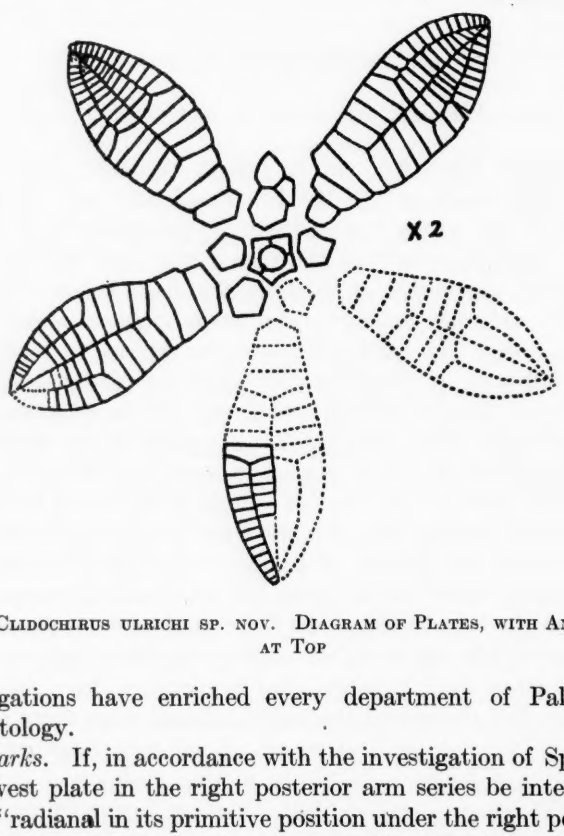


FIG. 1. CLIDOCHIRUS ULRICHI SP. NOV. DIAGRAM OF PLATES, WITH ANAL SIDE AT TOP

investigations have enriched every department of Palaeozoic Paleontology.

Remarks. If, in accordance with the investigation of Springer, the lowest plate in the right posterior arm series be interpreted as the "radianal in its primitive position under the right posterior radial," then the first costal of the preceding description becomes the radial, and the right posterior arm is credited with only two,

in place of three costals. In that case it is evident that the specimen here described has two radianal plates, the primitive radianal plate at the base of the right posterior arm and the secondary radianal plate wedged in between the primitive radianal and the anal x plates. It is not known to what extent this secondary radianal plate will be found to be a constant feature in this species.

Compared with the Brassfield species of *Clidochirus* described and figured by Springer, and also described in this paper, the crown of *Clidochirus ulrichi* is elliptical ovate rather than inversely conical in form. The sides of the calyx are more divergent and the greatest width of the crown is near mid-length. All of the arm plates are relatively shorter and wider, especially in case of the costals and distichals.

Myelodactylus (Eomyelodactylus) rotundatus

sub-gen. et sp. nov.

Plate I, fig. 8; plate II, fig. 3

Fragment of column, coiled, about 115 mm. in length, broken off where the reversal of curvature begins, possibly within 25 mm. of the base of the crown. The greater diameter of the stem, measured from the convex to the concave side of its curvature, equals 2.25 mm. throughout almost the entire length of the fragment, but at a distance of 5 mm. from the beginning of its reversal in curvature this diameter diminishes rapidly and is reduced to 1.4 mm. at the broken end. It probably continued to diminish in size gradually toward the crown. The diameter at right angles to the one just discussed is a little less, thus producing a slightly elliptical cross-section.

The length of the columnals varies. The first three columnals at the broken end, where reversal begins, occupy a length of 1.5 mm.; the next three, 1.9 mm.; the next three, 2.0 mm.; the next three, 2.3 mm.; then the length of the columnals remains constant until a point opposite the broken end has been reached. Then the length diminishes to three columnals in 1.8 mm., remains

constant for about one-third of a volution, and diminishes to three columnals in 1.5 mm. at the end of the last third of a volution.

Throughout by far the greater part of the length of the column the latter has been split in two along a plane parallel to the plane of curvature. This exposes a darkened line, never more than three-tenths of a millimeter in width, which evidently locates the lumen. The latter is distinctly nearer the convex side of the curvature of the column, and, in transverse sections of the stem, is seen to be wider in a direction at right angles to the plane of curvature. Under a lens it appears possible to detect four additional planes, indicated by slightly darker coloring, suggesting original pentamerism (plate II, fig. 3) with the unpaired segment on the convex side of curvature of the column. Why this unpaired segment should split so smoothly along its middle is unknown, but the immediately opposite suture evidently is the one along which the stem should split most readily.

There is no conclusive evidence of the presence of two rows of cirri, nor of points of attachment for the latter, although vague traces of short cirri appear to be present at one point.

Locality and position. Holotype found up stream from Silver Springs, on the head waters of Caesars Creek, 4¾ miles southeast of Xenia, Ohio. The locality is over a mile and a half up stream from the Xenia-Wilmington pike. Here it occurs in the upper half of the Brassfield limestone, associated with the following fauna: *Cyathophyllum facetus, Halysites catenularia, Hemitrypa ulrichi, Chasmatopora angulata, Clathropora frondosa clintonensis, Phaenopora expansa, Ptilodictya expansa, Ptilodictya americana, Pachydictya bifurcata, Pachydictya obesa, Rhinopora verrucosa, Rhipidomella hybrida, Platystrophia daytonensis, Leptaena rhomboidalis, Brachyprion* moderately convex, *Strophonella daytonensis, Strophonella hanoverensis, Atrypa marginalis, Cyclonema daytonense, Illaenus ambiguus, Illaenus daytonensis, Proetus determinatus,* and *Encrinurus thresheri.*

Remarks. The reversal of curvature at the broken end of this column is indicated by the distinctly greater length of the last three columnals along the inner side of the coil. This suggests

the reference of the column to *Myelodactylus* or *Herpetocrinus*, two terms regarded at present as applying to the same genus. In hitherto described species of this genus the column is distinctly concave longitudinally along the inner side of curvature of that part of the column which bears the two rows of cirri. In the Brassfield species here described there is no trace of such a concave indenting of the outline of the columnals along the inner curvature of the column, and, hence, the Brassfield specimen is regarded as representing an earlier stage of development than typical *Myelodactylus*, and the subgeneric term *Eomyelodactylus* is here proposed with this Brassfield specimen as a type. In American strata, *Myelodactylus* is not known in strata earlier than the Rochester shale of New York and the Laurel limestone of Indiana, another species being known from the Waldron of Indiana, and a fourth from the Racine of Bridgeport, Illinois.

Botryocrinus sp.

Plate II, figs. 4 A, B

Calyx imperfect, more or less distorted by obliquely vertical compression, and with only parts of the upper margin of several of the infrabasals preserved. Basals, radials, radianal, and anal x plates similar in outline and general form to *Botryocrinus polyxo* Hall, from the Waldron shale of Indiana, but the latter attains a much larger size, and the facets for the reception of the arms are more vertically inclined. The maximum width of the calyx here described is about 13 mm. Although probably representing a new species, not enough remains of the specimen at hand to reveal any distinguishing characteristics.

Locality and position. In the *Holophragma* zone at the top of the Upper or Lilley division of the West Union formation, in the Zink or Corporation quarry, in the eastern part of Hillsboro, Ohio.

Mesopalaeaster (Hemipalaeaster) schucherti sp. nov.

Plates IV, V

Measurements: disk imperfectly preserved; its radius, measured from the center to the nearest part of the interbrachial arc, estimated as between 10 and 12.5 mm. Length of rays, measured from the basal radial to the tip, 25 mm.; distance from center of disk to tip of rays estimated as between 34 and 36.5 mm. Ratio of the longer radius, from the center of the disk to the tip of the rays, compared with the shorter radius, to the nearest part of the interbrachial arc, between 3.4 and 3, probably nearer the latter.

Abactinally, the disk is limited by an interrupted circle of large plates, consisting of the basal supramarginals (*S*, in figure on plate V), the dorsal interradials (*i*), and five plates (*r*), one at the base of each ray, interpreted as basal radials. The basal supramarginals tend to be pentagonal in outline and the dorsal interradials are more or less broadly triangular or rhomboidal triangular, with the blunted apex of the triangle directed toward the suture between the basal supramarginals. In the accompanying figure, these outlines are best indicated in the interbrachial areas between rays I and V. In the other interbrachial arcs, the dorsal interradials tend to have a shallow indentation on the proximal margin. In the arc between rays I and V, the proximal halves of the basal supramarginals are separated by a rhomboidal triagonal area (*m*) filled by a material distinctly darker than that of the abactinal plates, and, although occupying the position of a madreporite, its interpretation as such is extremely doubtful, especially in view of the absence of distinct radial striations. Similar dark material appears to occur in the sutures between some of the other plates on the abactinal surface. The plates interpreted as basal radials (*r*) are broadly pentagonal, with the very obtuse apex directed toward the distal end of the rays. In the accompanying figure, its outline is best shown on ray V, its blunt apex being directed slightly downward and toward the right, the plate being slightly displaced.

Between the basal radials and the nearest basal supramarginals there are one or two narrow, transversely elongated plates. The integument of the abactinal part of the disk apparently broke loose from the proximal end of rays III and IV, and contracted toward the opposite side of the disk, causing the disk plates on that side to be thrust more or less beneath the ring of plates forming the margin. Possibly the circular plate, marked *C* in the accompanying figure, is the centro-dorsal. Several plates of nearly equal size are slightly reniform in outline, but their original location is uncertain. Apparently, the remaining plates of the disk were of smaller size, some of them much smaller than others, but nothing can be said of their arrangement. In the accompanying figure the larger cross indicates the center of the disk as suggested by the present arrangement of the ring of marginal plates. The smaller cross gives another possible position for this center, if shrinkage of the integument be supposed to have caused a moderate lateral spreading of that part of the marginal ring which remained intact.

Abactinal area of rays consisting distally of three columns of plates, the two columns of supramarginals and the intermediate column of radials. The radials here are distinctly smaller than the supramarginals, forming with the latter transverse groups, each consisting of three plates, the spaces in the angles between two consecutive radials and the two adjoining supramarginals, on each side, being apparently vacant. The distal margin of each radial tends to overlap slightly the proximal margin of the adjoining radial. The proximal margin of the supramarginals tends to overlap slightly the distal part of the two adjoining supramarginals, while that part of the lateral margin which adjoins the neighboring radial is slightly pointed and tends to overlap the margin of this radial. That part of the ray in which the column of the radials is distinctly defined forms about seven-tenths of its length. Proximally, for the remaining three-tenths of its length, it is difficult to determine with certainty which plates are to be regarded as belonging to the column of radials. In the accompanying figure, on plate V the outlines of the radials, in the distal parts of the rays, and also the outlines of the sup-

posed radials, in the proximal parts of the rays, have been darkened. Only a small portion of these supposed radials is seen in certain cases, due to hiding beneath the overlapping accessory plates, intervening between the columns of radials and supramarginals. Proximally, there appear to be two columns of the accessory plates. These plates are ovate in outline, the more or less pointed ends being directed diagonally both toward the distant end of the ray and toward the radials, more or less overlapping the latter. The original arrangement of plates appears to have been disturbed least in the proximal parts of ray II; in ray V, the basal supramarginal and the two adjacent plates of the same series have been crowded inward, permitting only the tips of several of the adjacent accessory plates to show; otherwise the plates of the proximal part of this ray are but little disturbed.

The number of supramarginals in each column, exclusive of the basal supramarginal, apparently varies between 17 and 19, of which the distal two or three are much smaller than those immediately preceding. The most distal accessory plates occur at the side of the fifth, sixth, or seventh of the supramarginal plates, not counting the basal plate of the series. It is difficult to interpret the distal parts of rays II and IV without assuming the presence of supernumerary plates in the radial series, one or two supernumerary plates occurring also in three of the supramarginal series.

All of the rays expose some of the inframarginals, the longest continuous series being exposed on the sinistral side of ray I and on both sides of ray II. The number of these inframarginals appears to be slightly greater than that of the supramarginals, so that while they alternate with the latter proximally, they are even with them laterally in more distant parts of the ray, and become alternate again farther on. The inframarginals are larger in size then the supramarginals at least in the distal parts of the rays. They form the margins of the rays and extend from the abactinal to the actinal side of the rays, and are seen best on lateral view. No ambital or accessory plates occur between the columns of supramarginals and that part of the series

of inframarginals which is exposed immediately adjacent in case of any of the rays. In ray II, the inframarginals are in contact with supramarginals as near as the sixth supramarginal, not counting the basal plate of this series. In ray I, they are in contact as near as the fifth supramarginal. On the sinistral side of ray V, the nearest inframarginal alternates with the sides of the fourth and fifth supramarginal. This suggests that if any ambitals exist the latter must be restricted to more proximal parts than any here exposed and that their number must be small.

The actinal side of the rays is exposed by the tip of ray V (see figure VB on plate IV) for a length of 15 mm. The inframarginal plates form the sides of the rays and the adambulacral plates form two additional rows, one on each side of the ambulacral groove. In number, the adambulacrals appear to equal the inframarginals, and to be directly opposite the latter, but they are of less width. The plates seen at the bottom of the ambulacral groove are interpreted as ambulacral plates, but they are not exposed well enough to permit of accurate description.

The surface of the plates, where unweathered, is minutely granular, about four granules occurring in a distance of half a millimeter.

Locality and formation. Five and a half miles west of Hillsboro, Ohio, at a quarry reached by going from Fairview crossroads half a mile east and then three-quarters of a mile southward, to the southern side of the head-waters of a small stream. Here, the specimen described, a holotype, was found in the thinner-bedded layers at the top of the quarry, associated with *Brockocystis nodosarius, Hallopora magnopora, Orthis flabellites, Strophonella daytonensis,* and *Plectambonites transversalis.* These thin-bedded limestone layers occur 11½ feet above the base of the quarry. The base is formed by the more massive cherty layers which occur a short distance above the base of the Brassfield formation. Named in honor of Prof. Charles Schuchert, in recognition of his many services to American Paleontology.

Remarks. The most striking feature of *Mesopalaeaster schucherti* consists in the radial plates forming a distinctly recognizable series only along the more distal parts of the rays, and in

the radial accessory plates being confined to the proximal parts of the rays. In the more proximal parts of the rays it is impossible to pick out, with any degree of confidence, those plates which are to be regarded as belonging to the radial series. The nearer accessory plates either equal or exceed the radials in size, and the latter either are partially covered or are more or less displaced, so that they can not be identified as radials. While not in the direct line of descent from *Hudsonaster* to *Palaeaster*, this species indicates how *Palaeaster* may have originated by the introduction of radial accessory plates and by the displacement of the radials, the latter diminishing in size and finally disappearing altogether distally.

It is evident that the genus *Mesopalaeaster* will be broken up into various subgenera or genera as the species at present referred to this genus become better known. The beginning has been made by W. K. Spencer, who founds the new genus *Caractacaster* on the Ordovician species *Palaeaster caractaci* Gregory, from the Caradoc sandstone of Wales and of the Welsh border, characterizing this genus by the presence of a continuous series of radials, bordered on each side by a column of small radial accessory plates which extends the entire length of the rays. For *Mesopalaeaster schucherti* the subgeneric name *Hemipalaeaster* is proposed, in view of the partial loss of a distinct series of radials, in the proximal parts of the rays.

Schuchertia magna sp. nov.

Plate VI, fig. 1

Measurements. Radius of the disk, from its center to the nearest part of the interbrachial arcs, 13 mm. Radius from the center of the disk to the tip of the rays, 33 mm.; longer radius about 2.5 times the length of the shorter radius.

Rays separated by large interbrachial arcs, narrowing rapidly near the base, so as not to exceed 7 mm. in width at a distance of 14 mm. from the tip; narrowing thence more gradually and terminating rather bluntly.

Abactinal area composed of numerous small plates. These plates are very small near the tips of the rays and gradually increase in size toward the disk, numerous plates on the disk equalling 2 mm. in diameter. Nothing is known of the arrangement of the plates except along the distal halves of the rays where the plates are aligned in slightly oblique rows, as indicated on rays A and B of the accompanying figure. Apparently five or six of these rows occupied the width of the ray between 6 and 12 mm. from its tip. In the present state of preservation of the specimen, the larger plates, on and near the disk, appear to be irregularly interspersed with smaller plates. In the accompanying figure, the larger plates are shown best on the left side of the disk, between rays B and D.

Nothing definite is known of the surface of the plates, but a few of them present the appearance of having been strongly elevated at the middle into a prominent node.

Locality and position. The holotype was found about $5\frac{1}{2}$ miles east of West Union, $1\frac{1}{5}$ miles east of the Stone Church, where the road crosses a small creek. Here the specimen was found in the Brassfield limestone at the top of a small fall immediately beneath the bridge, 30 feet below the base of the Dayton limestone, at about the same horizon as the holotype of *Mesopalaeaster schucherti,* although the latter was found $5\frac{1}{2}$ miles west of Hillsboro, Ohio.

Remarks. This specimen is of interest chiefly on account of its occurrence in the Brassfield formation. At the time of its discovery it appeared scarcely worth collecting. In outline it closely resembles *Schuchertia laxata* Schuchert, but it is distinctly larger and the plates on the disk appear to have been much more irregular in size. If these plates were strongly nodose centrally, this alone would be sufficient to distinguish it from the few species of *Schuchertia* hitherto described.

The possibility of the plates being nodose centrally is suggested by an anomalous specimen (fig. 7 on plate II) found, associated with *Brockocystis nodosarius,* in the lower part of the Brassfield formation, on a hill-crest a mile northeast of the center of Manchester, Ohio. It is not known even that this specimen

is part of a starfish, but if the nodose projections were removed the plates would at least be similar in size and irregularity. The larger of these plates are 2 mm. in width and the central nodose projections are slightly over 1 mm. in width. Smaller plates have correspondingly narrower projections. All plates are of about the same thickness, about 0.8 mm., and the nodose elevations vary from a little over 1 mm. on the larger plates to about 0.6 mm. on the smaller ones. The width of the nodose elevations is slightly greater at the top than at mid-length, and they may have served as supports for spines.

Stereoaster squamosus sp. nov.

Plate VII, figs. 2 A, B, C

In its present state, the echinoderm here figured and described resembles a starfish, and as such it is here described, although structurally differing from all of the three major subdivisions of the Palaeozoic Stelleroidea so far proposed—the Asteroidea, Auluroidea, and Ophiuroidea.

Rays five, slender and gradually tapering, separated by distinct interbrachial arcs. The radius of the disk, from the center of the disk to the interbrachial arcs, varies from 4.5 to 5 mm. None of the rays is preserved as far as its tip, but from such parts as are preserved it is estimated that the radius from the center of the disk to the tip of the rays equals about 18 or 19 mm. In two of the interbrachial arcs the outline of the disk is moderately convex rather than concave.

Only the actinal side of the specimen is exposed, but this side of the specimen appears considerably worn so that almost all of the plates actually exposed undoubtedly belong to the abactinal part of the integumentary skeleton, only the inner surfaces of the abactinal plates being visible in most cases.

In the interbrachial area between rays I and V, as designated on the accompanying figures, there is a broad, flat, scale-like plate. Between this plate and the center of the disk, the bevelled-off inner margins of at least four additional similar plates are exposed. These plates overlap each other in such a manner

that in each case the slope is from the upper, distal margin toward the lower, proximal margin of the plate, forming an angle of about 15 degrees with the horizontal plane of the specimen. The surfaces of contact between these plates are finely striated in a direction perpendicular to their inner margins, similar to the striations on the inner surfaces of contact on some of the larger scales of some of the Ordovician Agelacrinidae. In the specimen here described these plates evidently were closely articulated, and probably were held rigidly together, or were only slightly movable.

In the interbrachial arc between rays I and II, and also between rays IV and V, there are several plates of which those near rays I and V are shorter, while those near rays II and IV are longer, in a radial direction. When viewed from the interior of the disk, these plates or series of plates tend to slope in the same direction as those between rays I and V, already described.

Large, flat, scale-like plates are present also between rays II and III, and between rays III and IV. These also are finely striated in a direction from their distal toward their proximal margins, along their surfaces of contact. They slope somewhat as the interbrachial plates between rays I and V, rising laterally toward rays II and IV, and inclined more or less downward toward ray III.

Mr. Austin H. Clark, of the United States National Museum, kindly showed the writer various Ophiuroidea with more or less overlapping scale-like plates, but in these Ophiuroidea the symmetry was plainly radial, while in the specimen here described the symmetry seems more bilateral, as far as the arrangement of the scales of the disk are concerned. Unfortunately the upper surface of the disk is not visible. On the basis of at least partial bilateral symmetry, the interbrachial arc between rays I and V is regarded as the posterior part of the disk.

The outlines of the inner surfaces of the abactinal plates of the rays are exposed best in case of ray IV. As here exposed, the plates are irregular in size, form, and arrangement; there appears to be no arrangement in longitudinal series, corresponding to the radials, marginals, and inframarginals among the

Stelleroidea. In its present state of preservation, the most striking feature of this ray is the irregular series of short vertical pores along the anterior side of the concave depression traversing the actinal side of this ray longitudinally. These pores vary from 0.25 to 0.33 mm. in depth, and tend to occur in pairs, the members of each pair being less than 0.5 mm. apart, or sometimes so close together that two pores are included in the same general depression, appearing as separate pores only at the bottom of the larger elliptical pore formed by their union.

A similar irregular series of vertical pores occurs along the anterior side of the longitudinal depression following the actinal side of ray II. Pores are not seen on the proximal parts of ray III, but on the distal part several pores occur along the middle of the longitudinal depression there visible. Vertical pores exist also along the middle of the deep depression following the actinal side of ray V. In the case of ray I, that part of the longitudinal depression which might show pores is over-arched by other plates, not seen on the other rays, probably because not preserved there. No explanation for the presence of these pores can be offered. They appear closed at their inner extremities, and apparently bear no relation to the podial canals among the Auluroidea. At first they were regarded merely as borings, subsequent to the death of the animal, but in that case there appears to be no reason why their presence should be confined practically to definite parts along the longitudinal depressions following the actinal side of the specimen. The depression marked *a* in figure 2C on plate VI accompanying this paper probably represents an ordinary boring, and is quite different in size and depth from the pores just described. Moreover, there is no appearance of pairing in this case.

The plates forming the abactinal side of the specimen, and these are almost the only plates here exposed, are so thick, and are so closely appressed at the sutures, that they must have been almost immovable. The thickness of the plates varies between 0.6 mm. to almost an entire millimeter, and may exceed this amount in some parts of the specimen, nearer the disk, where measurements, in the present state of exposure of the specimen, are impossible.

In the case of ray I, what is regarded as the ambulacral groove is overarched, at least proximally, by a number of small plates not seen on the other rays. The outlines of only a few of these small plates can be distinguished, and these do not suggest any analogy with the ambulacral and adambulacral plates among the Asteroidea. The arching plates, except at the proximal end of the ray, appear to be thin, and appear to sag readily into the ambulacral groove. Similar over-arching plates may have existed formerly over the proximal ends of the ambulacral grooves of all of the other rays, but, in the present worn condition of the specimen no trace of these plates can be detected. The proximal half of ray III at present shows no trace of the ambulacral groove, probably on account of weathering, but the longitudinal depression formed by this groove is retained on the distal half of the ray, and here the short vertical pores already described occur along the central part of this depression.

Locality and position. Associated with *Dimerocrinus* (?) *vagans*, within 2½ feet from the top of the Brassfield limestone, at a locality reached by going from Byron, Ohio, 1 mile east and then 1 mile southeast. The exposure occurs in a shallow wet-weather stream bed, east of the road. In a direct line this exposure is less than seven miles northwest of Xenia.

Remarks. The affinities of this species among the Echinodermata are highly problematical. The arm structure does not resemble even remotely that of the Ophiuroidea or Auluroidea. The entire absence of any structure resembling ambulacrals and adambulacrals excludes it from the Asteroidea, even from the Cryptozonia division of the Asteroidea. The specimen here figured and described is the only one found in many years of collecting, and there seems no prospect of securing additional illuminative material in the near future; hence its present publication.

The excellent photographs forming the basis of the accompanying figures were prepared by Dr. Herrick E. Wilson, of the U. S. National Museum.

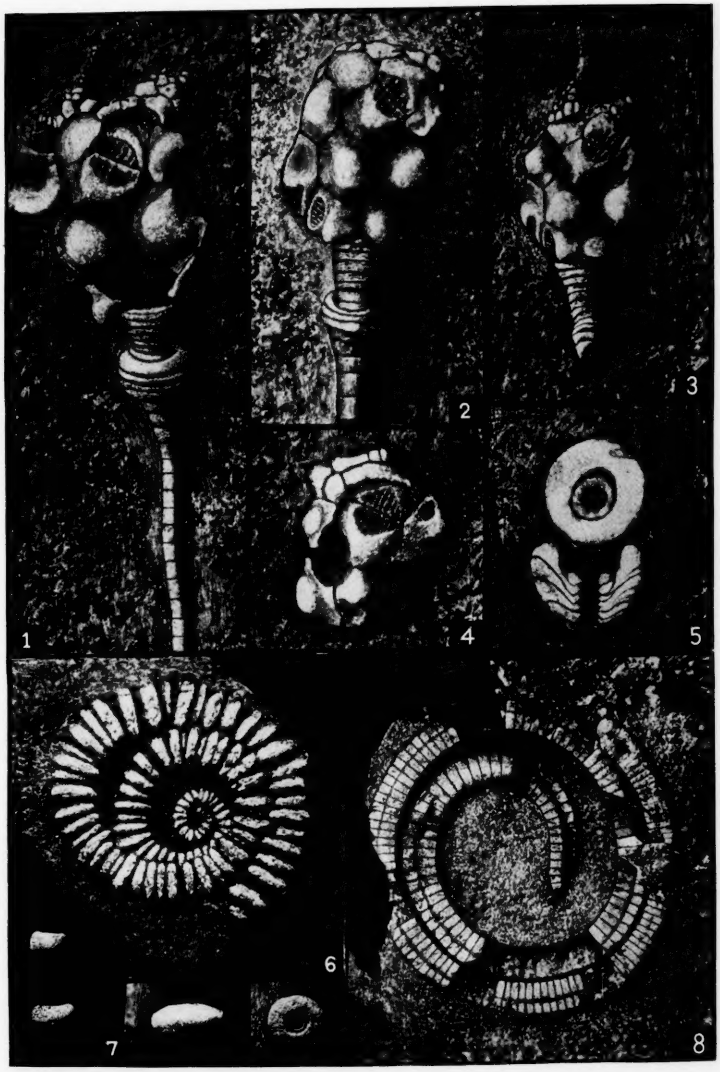
PLATE I

Figs. 1–5. Brockocystis nodosarius sp. nov. The pectinirhomb on plates 12–18 is seen in figures 1, 2, and 3; the last two of these figures show also the pectinirhomb on plates 1–5; in each figure the anal area is on the right, the two plates bordering on the left side of this area being included in the figure. Figures 1 and 3 show traces of the brachioles. The pectinirhombs on plates 14–15 and 10–15 are shown by figure 4; the anal area is included in the lower left hand corner of the figure. The pyriform enlargement of the column, a short distance below its top, is shown in figure 5, presenting both a horizontal and a vertical section, indicating the origin of this enlargement from the coalescence of a number of columnals. All figures enlarged 2.7 diameters. From 2 miles west of Peebles, Ohio; Brassfield formation.

Fig. 6. Coiled crinoid stem. From Brassfield formation, 1 mile northeast of Wilberforce, Ohio. For illustrations of separate columnals see plate II, figures 5A, B, C.

Fig. 7. Brockocystis tecumseth (Billings). Enlargements of the top of the column, due to coalescence of several of the columnals. Three lateral views, showing variation in outline; one specimen viewed from the top, showing area of articulation. Cataract formation; half a mile east of Ice Lake, on road from Gore Bay to Kagawong, on Manitoulin Island. Shown in contrast with similar enlargements of the column in *Brockocystis nodosarius*.

Fig. 8. Eomyelodactylus rotundatus sp. nov. Coiled column, terminating at the center at the point where reversa of curvature took place. In by far the greater part of its length this column has been split in half, and only the split surface is seen, exposing the lumen. See plate II, figure 3, for a cross-section of this column. Brassfield formation; nearly 5 miles southeast of Xenia, Ohio.



FOERSTE: OHIO BRASSFIELD ECHINODERMATA

PLATE II

Fig. 1. Clidochirus ulrichi sp. nov. A. Enlarged view of calyx and arms, showing the anal side. B. Same specimen, with column attached. Dayton limestone; southeast of Soldiers' Home, west of Dayton, Ohio.

Fig. 2. Lepadocystid plate. Single plate of unknown species of Lepadocystid. Brassfield formation; 1 mile northwest of Cowlesville, Ohio.

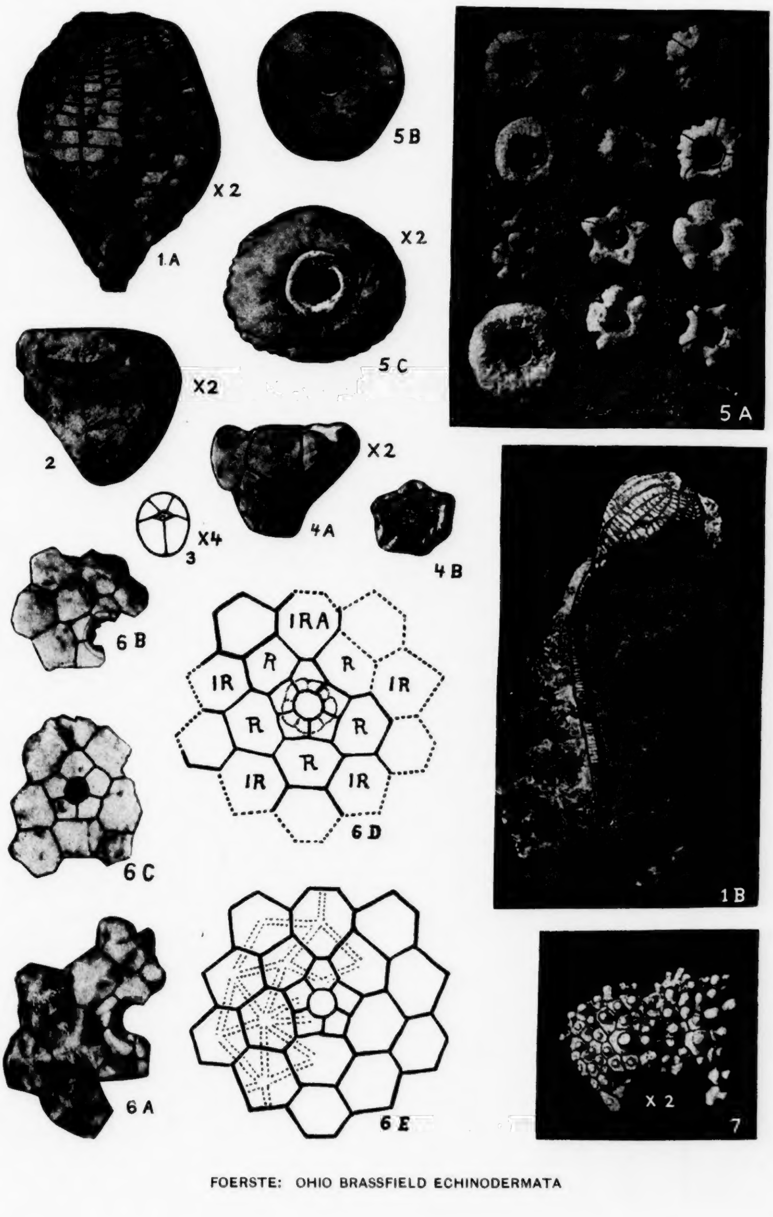
Fig. 3. Eomyelodactylus rotundatus sp. nov. Cross-section of column of specimen represented by figure 8, plate 1.

Fig. 4. Botryocrinus sp. A. Lateral view of calyx, anal side. B. Top view of same specimen. Holophragma zone at top of Upper or Lilley division of West Union formation; Zink quarry in eastern margin of Hillsboro, Ohio.

Fig. 5. Crinoid columnals. Columnals of same species as that forming the coiled column illustrated by figure 6, plate I. A and C from Soldiers' Home quarry, west of Dayton; B from Centerville quarry, Ohio.

Fig. 6. Dimerocrinus (?) vagans sp. nov. A, B, and C. Fragments of the base of calyces, all with anal side at top of figure; A, B, exterior views; C, view from interior side of calyx. D. An attempt at a restoration of the basal part of the calyx, based on various specimens. E. Figure indicating the direction of the radiating lines ornamenting the plates. Brassfield formation; about 1½ miles southeast of Byron, Ohio.

Fig. 7. Echinoderm plates. Numerous small plates of an echinoderm, each plate ornamented by a small central abruptly elevated protuberance. For description, see paragraph following remarks on *Schuchertia magna*.



FOERSTE: OHIO BRASSFIELD ECHINODERMATA

PLATE III

Fig. 1. Brockocystis tecumseth (Billings). Basal view of theca, showing large lumen at area of attachment, the pectinirhomb on plates 1–5, and the reticulated surface of the plates. For additional illustrations of the same specimen, see Bull. Sci. Lab. Denison Univ., vol. 17, pl. V., figs. 2A, B, C; the characteristic globular or pyriform aggregations of columnals of this species are figured on plate I of the present paper. From Manitoulin Island, east of Ice Lake, on the road from Gore Bay to Kagawong.

Fig. 2. Undetermined crinoid. Basal part of calyx of some unknown crinoid, with five infrabasals. Top of Brassfield formation; southeast of Byron, Ohio.

Fig. 3. A Platycrinid (?). Calyx and arms apparently belonging to the Platycrinidae; however, the margins of the plates are not defined clearly enough for accurate determination. From the soft clay at the top of the Brassfield formation at Centerville, Ohio. *Platycrinus corporiculus* Ringueberg (Bull. Buffalo Soc. Nat. Sci., vol. 5, 1886, p. 12, pl. I, fig. 9) from the Rochester shale at Lockport, N. Y., is a somewhat similar dubious form.

Fig. 4. Cyathocrinus (?) sp. Parts of a crinoid with very thick plates, possibly a *Cyathocrinus*. A, a radial followed by two costals, the axillary costal supporting two arm-branches, of which only the left one is well preserved. The latter has three distichals, and again only the left branch of the succeeding arm-branch is well preserved. B, top of column with 2 very thick infrabasals still attached, also one of the basals. From the soft clay at the top of the Brassfield formation, at the Centerville quarry, Ohio. In vol. 3, Bull. Sci. Lab. Denison Univ., on plate 8, figure 42 presents one of the radials of this species, and figure 43 probably represents one of the basals. Figure 44 may be one of the axillary plates of the arm system. All of these earlier figured specimens were obtained from the soft clay at the top of the Brassfield formation, at Soldiers' Home, west of Dayton, Ohio.

1

X 6

X 2.8

2

X 2.8

3

X 1.3

4A

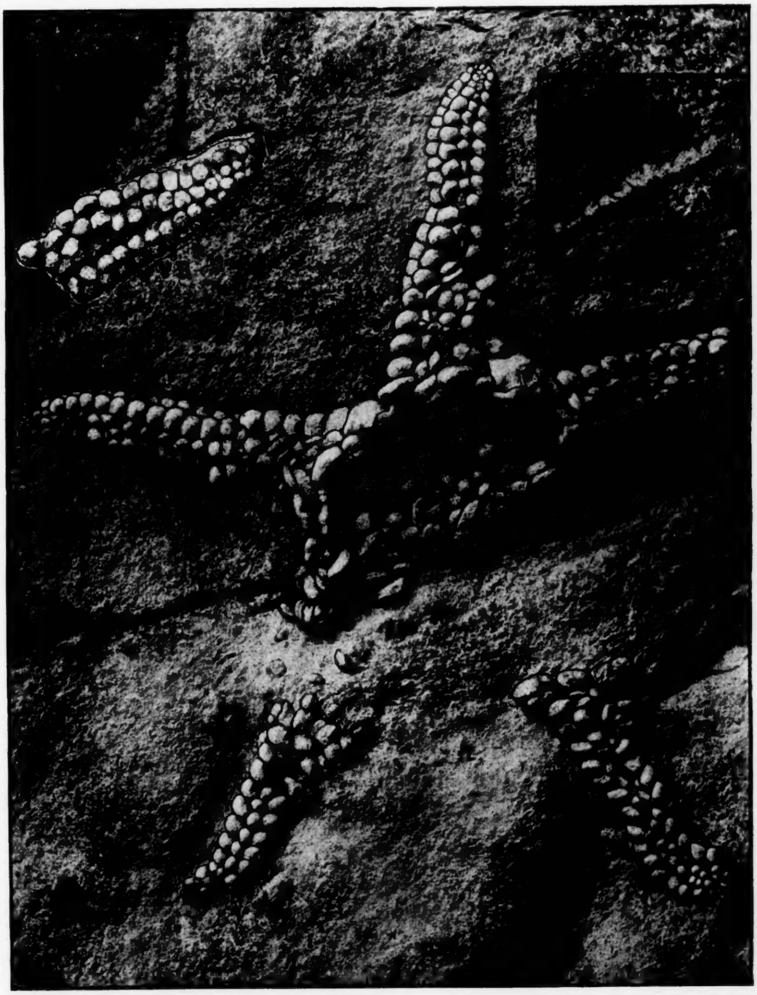
X 1.3

4B

FOERSTE: OHIO BRASSFIELD ECHINODERMATA

PLATE IV

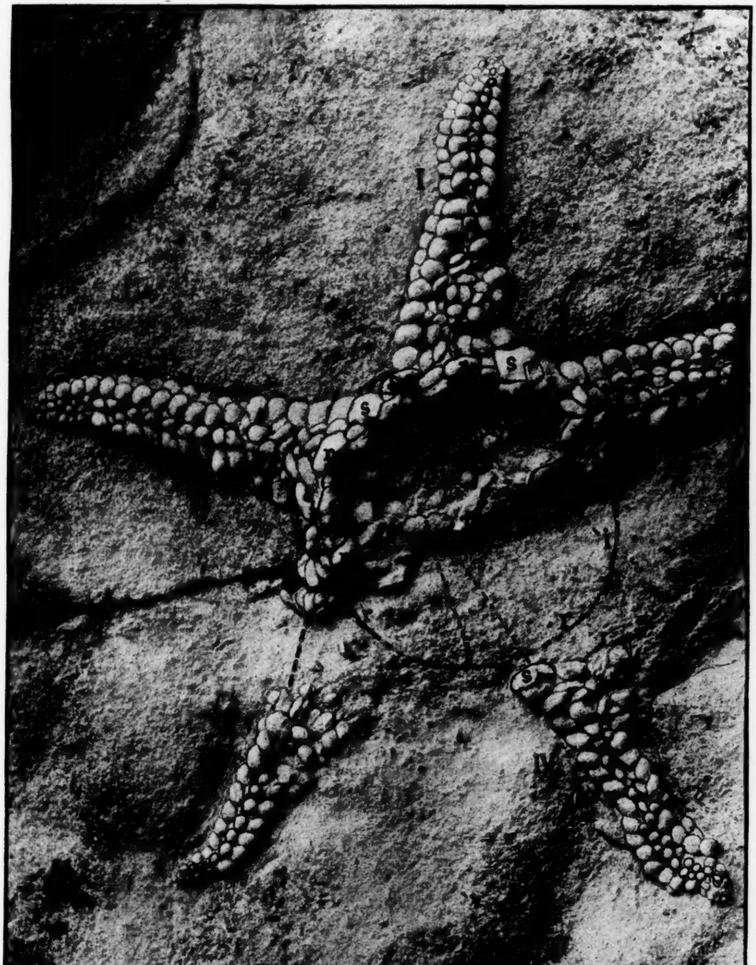
Hemipalaeaster schucherti sp. nov. Abactinal side of an almost entire specimen, enlarged about 2.1 diameters. Before complete burial, the margin of the disc appears to have rotted away from the proximal parts of rays III and IV, and to have shrunk away from the latter. In collecting the specimen, the tip of ray V broke off, and the impression left by this ray in the top of the limestone is shown by figure VA; the actinal side of this tip is represented by figure VB. The lateral margins of this second figure are formed by the inframarginals; the other two rows of conspicuous plates are the adambulacrals. For comments on the remainder of the specimen see the descriptive material accompanying the diagrammatic indications on plate V. From the top layers in the quarry, 5½ miles west of Hillsboro, Ohio, reached by going from Fairview cross-roads half a mile east, then three-quarters of a mile south, crossing the headwaters of a small stream to a quarry in the lower half of the Brassfield formation.



FOERSTE: OHIO BRASSFIELD ECHINODERMATA

PLATE V

Hemipalaeaster schucherti sp. nov. The rays are numbered from I to V. In each ray, the radial plates are indicated by darkening their outlines. In the distal parts of the rays this may be done with some accuracy; in the more proximal parts this is all guess-work. The basal supramarginals are indicated by *S*, and from these plates the remaining supramarginals may be traced readily as far as the tips of the rays. The inframarginals are well seen on the left side of ray I, and on both sides of ray II, along the more distal two-thirds of the rays. The dorsal interradials are indicated by *i*. The plates indicated by *r* may correspond to the basal radials of other species, but this is very doubtful. The former extent of the disc of this specimen is indicated by the broken circle. The two plates which are marked *i*, and which are enclosed by this broken circle, resemble the dorsal interradials in outline and are believed to have been located originally at the points on the circle with which these plates are connected by dotted lines. The original center of the disc probably was located near one of the two small crosses. The plate marked C may correspond to the centrodorsal of other species, but this is highly problematical. Moreover, the correct interpretation of the apparent opening toward the right of plate C is prevented by its poor state of preservation. If the plate marked M is the madreporite, it does not resemble the corresponding one in *Palaeaster niagarensis*. The arrangement and general appearance of the basal supramarginals and of the dorsal interradials, however, is similar.

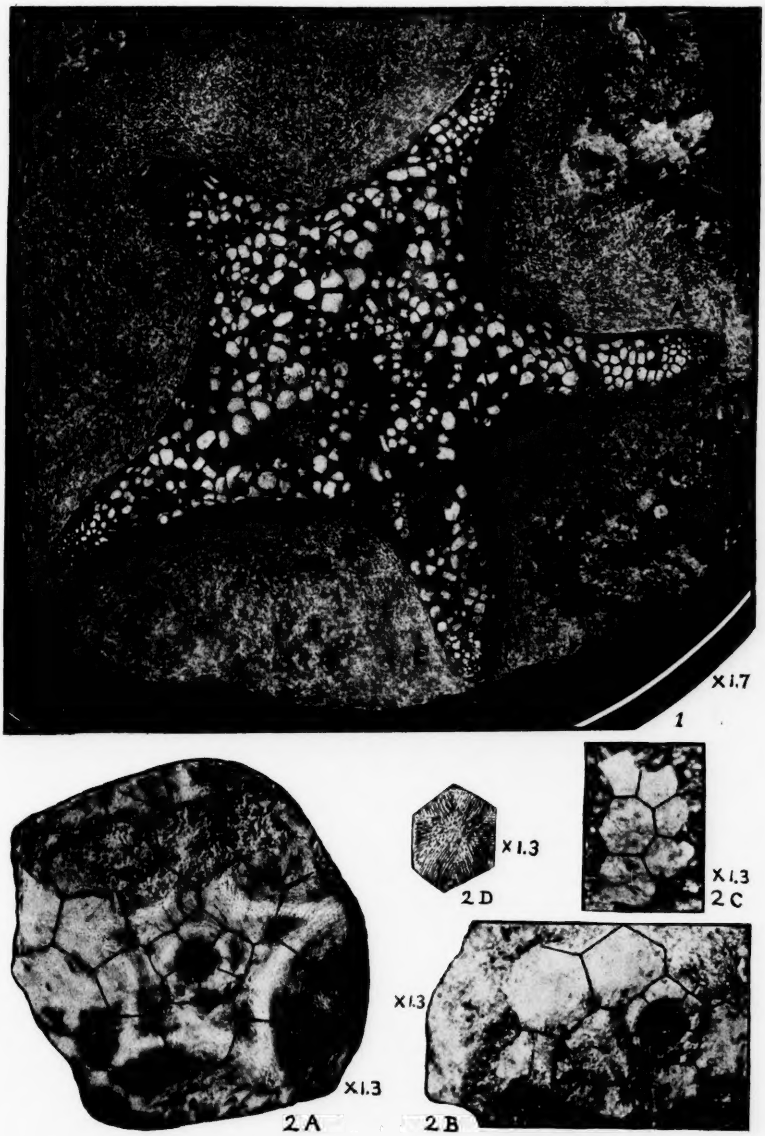


FOERSTE: OHIO BRASSFIELD ECHINODERMATA

PLATE VI

Fig. 1. Schuchertia magna sp. nov. A poorly preserved specimen, enlarged 1.7 diameters, photographed under water so as to bring out the individual plates. Most of these have been displaced. Near the tip of ray A most of the plates still occupy their original relative position; this is true also of some of the plates on the distal halves of rays B and E. Those of the central part of the specimen evidently have been much displaced. The specimen is valuable chiefly in presenting the general form and size of the species. About 5½ miles east of West Union, 1½ miles east of the Stone Church, where the pike crosses a small creek. Here the specimen was found in the Brassfield limestone, 30 feet below the base of the Dayton limestone, at the top of the limestone exposure immediately beneath the bridge. The horizon is regarded as approximately the same as that of *Hemipalaeaster schucherti*, although the latter was found over 5 miles west of Hillsboro, Ohio.

Fig. 2. Unknown crinoid. A, base of calyx with traces of the low ridges ornamenting the plates; in the figure these traces are emphasized. B, a second specimen, preserving better the articulating surface for the attachment of the column. C, several additional plates. D, one of the plates, preserving the surface ornamentation. From the area a mile and a half southeast of Byron, Ohio, at the top of the Brassfield formation. Figure 41 on plate 8, vol. 3, Bull. Sci. Lab. Denison Univ., appears to represent the same species. The same figure is seen on plate 27 of vol. 7 of the Ohio Geological Survey, published in 1895.

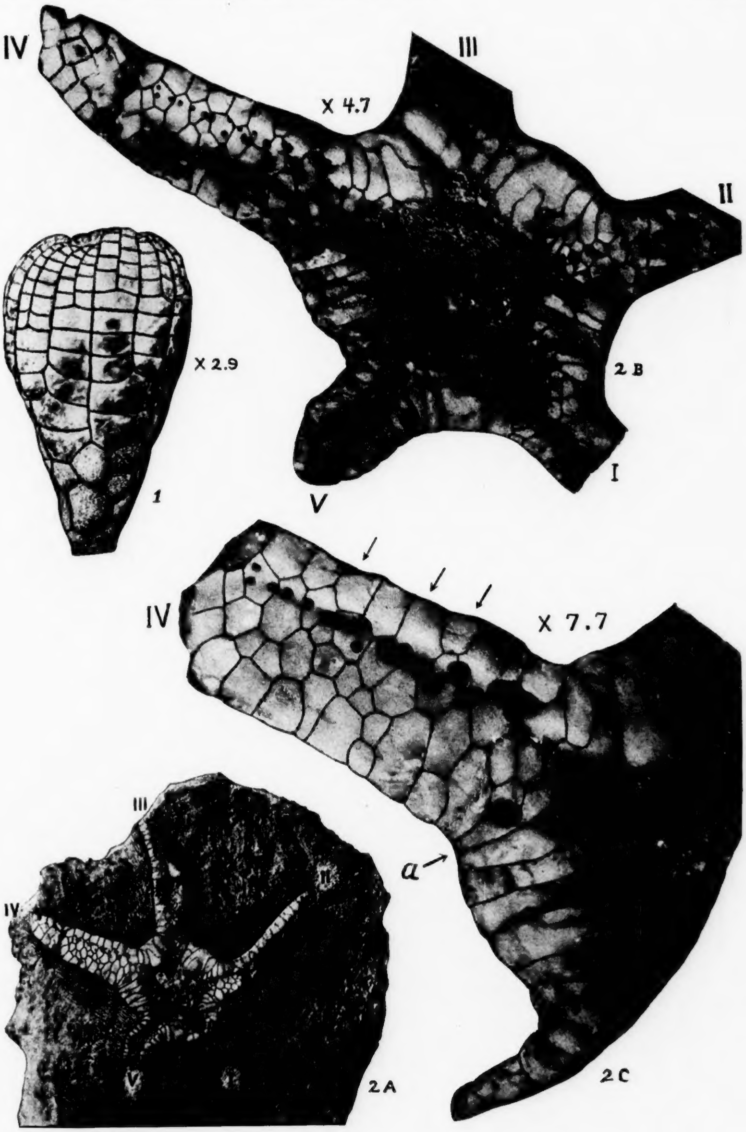


FOERSTE: OHIO BRASSFIELD ECHINODERMATA

PLATE VII

Fig. 1. Clidochirus sp. Species described by Springer. Anal side of calyx with arms attached. From the soft clay at the top of the Brassfield formation at the quarry northwest of the railroad station at Centerville, Ohio.

Fig. 2. Stereoaster squamosus sp. nov. A, entire specimen, actinal side. B, the greater part of the same specimen enlarged. C, a part of one of the arms enlarged still further. The arms are numbered with Roman numerals. The arrows in figure 2C point to depressions within which the pores are seen to occur in pairs; the letter *a* in the same figure points to a large pit for which there appears no structural reason. The overlapping of the plates within the central area is seen best within the lower, lefthand side of this area, and near the basal parts of ray II in figure 2B. There is no evidence of system in the arrangement of the plates, such as would be expected among the Stelleroidea.



FOERSTE: OHIO BRASSFIELD ECHINODERMATA

AMERICA'S ADVANCE IN POTASH PRODUCTION[1]

W. C. EBAUGH

INTRODUCTION

In a paper presented early in 1917,[2] it was pointed out that the world faced an emergency of greatest consequence, due to its inability to get potash for agricultural and industrial uses, and the hope was expressed that the Great War might lead to cheap potash, just as the Napoleonic wars of the preceding century had led to cheap soda. Events of the last two years apparently justify the belief that this hope has turned to fact, and that economic independence, so far as potash is concerned, has been won by a victory no less remarkable in its way than that achieved by arms.

The antitheses of war are striking. Men, women and children have pain, mutilation, starvation and death forced upon them, are torn loose from their abodes and possessions, and scattered broadcast as refugees; yet never are bravery, coöperative action, fellowship of all classes, and self-forgetfulness more in evidence. Science and industry run amuck, labor on a gigantic scale is turned from constructive to destructive work, the normal markets and trade routes are closed, and wastage is enormous; yet inventive genius, medical skill, sanitation, conservation, substitution of new raw materials for those no longer available, and the introduction of new methods of manufacture and distribution come to a nation's relief. National hate, greed, duplicity, rapacity, ruthlessness and cruelty find their counterparts in love and sympathy for one's allies, generosity to war victims at home and abroad, the introduction of "blue sky

[1] An address prepared for the regular semi-monthly meeting of the Denison Scientific Association, December 17, 1918.

[2] W. C. Ebaugh, Potash and a world emergency, Jour. Indus. Eng. Chem., vol. 9, p. 688, 1917.

diplomacy," and the abolition of secret treaties, the organization of benevolence on an unprecedented scale, and the expenditure of time and money to repair wastage—not for self, but for those who would have been considered aliens, beyond the pale of one's normal interest a few months ago.

It has been well said that the sinews of war are men, munitions or material, money and morale. In the second category come explosives and the enginery of war, clothing, shelter and food. And the greatest of these is food—food not only for men at the front, but for all the people of the nation at war. The maximum production of food without fertilizers is impossible, and Liebig's doctrines that phosphates, nitrogen and potash must be put into soils to replace these constituents removed with crops and transported to distant places, have found ever increasing acceptance since they were published some seventy-five years ago. Of these three plant foods, the Allies and the United States had access to phosphates and nitrogen in sufficient amounts, but in the case of potash, Germany was sole dictator. In fact, her control of this great natural monopoly constituted her "one big economic weapon" which she threatened to use in such a way that the nations of the world would be brought starving to her doors, begging for potash that they might have bread!

STASFURT DEPOSITS

The story of Stasfurt salt deposits is one of great interest. For centuries salt had been obtained from this district in north central Germany, near Magdeburg, and the deposits are known to be at least 100 square miles in area, with strata 3 to 4 inches thick and with some 15,000 "rings" or layers, indicating that the salt required at least 15,000 years for its deposition. Judging from workings down to the 3300 foot level, it has been estimated that brine, from which these salts came, would have covered the earth to a depth of 50 miles, that the temperature during at least a part of the time evaporation was taking place, varied from 80° to 160°F. and that "conditions for air evaporation were exceedingly favorable during the Permian period."

Borings were begun in 1837, salt was encountered in 1843, and shafts were sunk between 1851 and 1856. Disappointment ensued, because "bitter salts" and not rock salt, were found. But the value of these "bitter salts" as a source of potash was soon recognized. Frank, a sugar chemist, worked out a method

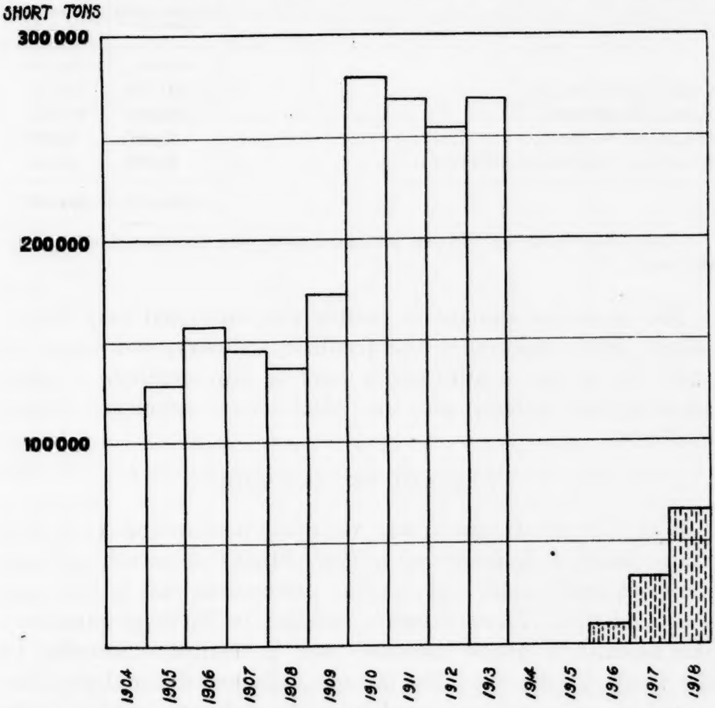


FIG. 1. Imports (open rectangles) and domestic production (shaded rectangles) of potash (K_2O) in United States 1904–1918.

for extracting potassium chloride from the mixed sodium-potassium-magnesium salts, and the first factory was erected in 1861. From that time until 1914 Germany monopolized the world trade in potash.

The extent of Germany's exports of potash to the United States is shown in the accompanying diagram (fig. 1). Although

both crude and refined salts are shipped, for purposes of comparison all are calculated to a "potash" or "K_2O" content. In 1912 the exports from the German Empire and the imports into the United States were:

	EXPORTS FROM GERMANY	IMPORTS INTO U.S.A.
	met. tons	*met. tons*
Crude potassium salts	1,300,559	650,297
Potassium chloride	286,528	190,775
Potassium sulphate	85,452	35,366
Potassium magnesium sulphate	48,540	14,172
	1,721,079	890,610*

* Equivalent to 65 cars, 100,000 pounds capacity, six days a week throughout the year.

This immense amount of potash was consumed very largely (about seven-eighths) in the fertilizer industry, and found its chief use in the south-eastern part of our country. Cotton, tobacco and cereals are the chief crops requiring potash fertilizers.

WAR AND THE BLOCKADE

With the catastrophe of war, the allied nations and the United States faced a desperate situation. Stocks of potash on hand were relatively small, and no other source than that in Germany was available. Even deposits—similar to those at Stasfurt—said to exist in Alsace-Lorraine, were in territory controlled by the Central Empires. The law of supply and demand was illustrated at once—prices soared from the ordinary level (a little under $40 per ton) to unheard of heights, but even then potash could not be had (fig. 2).

The technical press soon echoed Germany's boast that a starving world would be brought begging on its knees for potash fertilizers, and let it be known that this was the one great economic weapon possessed by the enemy. America's response was immediate. A search for potash, both on the part of governmental bureaus and of private parties, was begun, and the country

was examined as never before for this substance. Other nations joined in the search, but nothing comparable to Stasfurt could be found. Under these conditions, therefore, it is not strange that efforts were put forth to secure potash from industries of the "war-baby" type, and to recover it as a by-product from existing plants. The success attending these efforts is remarkable.

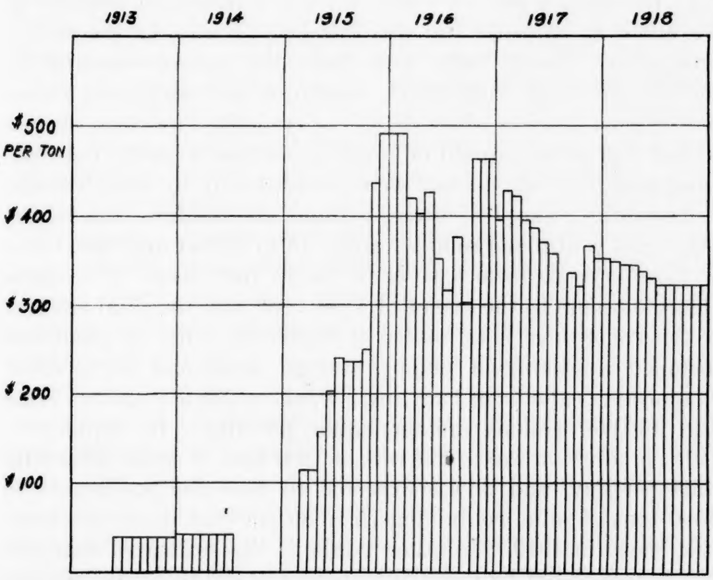


FIG. 2. Monthly prices in dollars per ton for "potassium muriate" (80 per cent), 1913–1918.

INORGANIC SOURCES

a. Lakes and brines. In 1912 some students from the University of Nebraska filed claims on certain alkaline lakes in the western part of their state, and during 1914 development of an alkali industry was begun. The treatment of the brine is very simple; it is pumped into settling tanks, evaporated in vacuum pans similar to those used in sugar factories, crystallized and

shipped in a crude state. The commercial product must contain 14 per cent of potash, but it is not difficult to maintain its content around 25 to 35 per cent. This industry has grown until a dozen or more plants are pumping brine from lakes over an area of 230 square miles. The major part of potash produced in this country during the first two years of the war came from the Nebraska lakes.

In the eastern part of California and neighboring portions of Nevada is an immense arid area that held promise for the potash prospector. Death Valley and Panamint, names associated in the popular mind with desert, desolation and starvation, represent typical districts where deposits were looked for; men seemed to feel that potash would be found as surface deposits, not realizing that those at Stasfurt were revealed only by deep borings.

At Searles Lake, California, is found the residue of an inland sea. Salt is firm and solid for about 15 to 25 feet and then brine or loose crystals form a layer 65 to 75 feet deep. Potassium chloride occurs to the extent of 4 per cent, and the total amount of this constituent is estimated at 24,000,000 tons. A plant was installed consisting of pumps, storage tanks and triple effect evaporators capable of handling 200,000 to 250,000 gallons brine and 100,000 gallons mother liquor per day. In September, 1918, production was at the rate of 1800 tons of crude potassium salts per day, and it was expected to raise the production to 4500 tons of salts, containing 75 to 80 per cent potassium chloride, early in 1919. In other words, it was estimated that this one source would be supplying about one-eighth of the pre-war consumption of potash.

At Salduro, on the Nevada-Utah border, and at Great Salt Lake, Utah, plants have been erected for the extraction of potassium salts by processes similar to those mentioned above, and much crude potash has been shipped to fertilizer factories and chemical plants. One company has operated for years at Great Salt Lake, making common salt and sluicing the mother liquors, rich in potash and magnesia, back into the lake. Its capacity was 100,000 tons of salt per year; the enhanced value of its products now that potash brings such prices, is self-evident.

During 1917 brines supplied more than 60 per cent of the total potash production in the United States.

b. Alunite. Alunite is essentially a basic sulphate of aluminum and potassium containing "potash" (K_2O) to the extent of about 11 per cent in the best varieties. At Marysvale, Utah, deposits have been developed on a large scale and a steady output of potassium sulphate has been maintained. At Sulphur, Nevada, are less well known deposits.

The treatment of alunite consists essentially of roasting the mineral, usually in rotary kilns of the cement-burning type, to drive off a part of the sulphur trioxide, convert the alumina into an insoluble form and the potash into a soluble sulphate. The last named salt is then extracted with water, separated from the insoluble residue, and recovered by evaporation. As no satisfactory method for disposing of the by-product alumina has yet been made, commercially, the industry is generally viewed as being of the "war-baby type," but capable of stabilization through development of by-products when readjustment to peace conditions occurs. During 1917 the production amounted to 2400 tons of potash, or about 8 per cent of the nation's output.

c. Cement kilns. At Riverside, California, a cement plant was compelled to abate its dust nuisance, and applied the Cottrell process of precipitation, i.e., passing flue gases between electrically charged conductors maintained at high potential differences. The removal of 95 per cent of the solids was attained with relative ease, and to the surprise of the technical staff it was found that a large portion of this recovered dust consisted of water soluble potash, or of material that could readily be made water soluble. It is another illustration of a fact so often seen in industry—a plant is forced to correct a nuisance, and the improvements installed yield valuable products that formerly escaped, thus adding to the earning power of the plant. Modifications of this process were installed later for cement plants located at Hagerstown, Maryland, Salt Lake City, Utah, and other points, and success so far attained indicates that the adoption of this or similar systems will become general, especially in the east.

d. Iron blast furnaces. Gases from iron blast furnaces must be cleaned before they can be used in gas engines. The Cottrell process mentioned above has proved its value in this service, and the ores of certain districts, Alabama in particular, contain such quantities of potash that recovery of this material becomes of great economic importance. Only 200 tons of potash were made from these sources in 1917—all of which came from experimental plants—but largely increased yields are expected in 1919.

R. K. Meade has estimated that an expenditure of $37,000,000 for potash recovery plants at iron and cement plants throughout the country would add 200,000 tons of by-product potash, or 80 per cent of our pre-war consumption, to America's output. This would be a low price to pay for economic independence in this line, and the amount involved seems small indeed when compared with war-time "drives" for $30,000,000 for Armenian and Syrian Relief, $170,000,000 for a United War Work Campaign, $200,000,000 for a Red Cross Fund or a $6,000,000,000 Fourth Liberty Loan! And the irony of fate is again evident. America's chemists and engineers have shown how to wrest Germany's "one economic weapon" from her hands by recovering and utilizing nuisance-creating material that is now allowed to go to waste on an enormous scale, by industries well established and easily able to provide necessary plants and technical skill.

e. Manufacture from silicates. For decades it has been recognized that the logical source of potash is silicate minerals, and much effort has been expended on developing processes to extract potash from feldspar, leucite (Wyomingite), glauconite or green sands, and similar material. Recently it has become general knowledge that tailings dumps often represent large quantities of locked-up potash; those at Cripple Creek, Colorado, run 10 per cent in potash, and those from the Utah Copper Company's mills, at Garfield, Utah, carry more than 6 per cent of this constituent. Such tailings are already finely ground and constitute the most accessible source of raw material for a silicate potash industry. The Utah Copper mills alone, treating 30,000 tons of ore daily, could supply enough raw material

(tailings) to yield 360,000 tons of potash annually, granting that only a 75 per cent extraction was made. This would be about 150 per cent of the pre-war consumption. And worthy of careful consideration is the fact that cement, also, could be obtained as a product from such a plant. The difficulties in the way are those of transportation and markets, rather than those of materials and processes; they are economic rather than technical.

Of the large number of methods proposed for treating silicates in order to obtain potash, heating with lime or magnesia and a chloride or sulphate of the alkali or alkali-earth metals, seems to be most highly esteemed. Mill tests have been so favorable that the adaptation of existing cement plants (as at Devil's Slide, Utah) and the erection of new plants (as at Green River, Wyoming) for the treatment of leucite, are now under way. Feldspar yields its potash less readily than does leucite, but even at that good extractions are to be had, and it is probable that only the fear of ruinous competition on the part of the German Kalisyndikat has prevented capital from entering this field more extensively.

Entirely unlike the processes outlined above are those proposed for utilizing glauconite or green sand. This material can be decomposed by water, or by water and carbon dioxide, under pressure at high temperatures, and quite pure potassium hydroxide or carbonate made in one operation. The by-product formed can be used for manufacturing building materials resembling sand-lime brick. Unfortunately deposits of glauconite in a sufficiently pure state are far less extensive than those of the other potash-bearing minerals.

ORGANIC SOURCES

a. Suint from wool washing gives potassium carbonate on ignition. About 300 tons of potash (K_2O) came from this source in 1917.

b. Beet sugar residues, especially those from the Steffens process, gave 360 tons potash in 1917.

c. Molasses from cane sugar factories, and *distillery waste* gave 2850 tons of potash in 1917.

All three of these sources are capable of great expansion, but cannot be viewed as main sources of potash. The last two mentioned contain nitrogen as well as potash, and are therefore doubly valuable as fertilizers.

d. Wood ashes. Until 1860 wood ashes constituted the most important source of potash, the supply coming chiefly from Canada and Russia. The introduction of Stasfurt salts in 1861 killed the industry. Normally not even the dust from incinerators at lumbering camps can be worked up profitably. During 1917, however, 425 tons of potash from this source were prepared in this country.

e. Kelp. The collection of kelp (seaweed) on the coasts of Scotland and France has been carried out for more than a century. The crop was then burned and used as a fertilizer. Like the wood ash industry it was snuffed out by Stasfurt potash in 1861, except in so far as it afforded a source of iodine.

During late years both governmental funds and private capital have been spent lavishly in investigating the possibilities of the Giant Kelps along the Pacific coast. These fields extend from Lower California to Alaska, and it was hoped that they would afford limitless supplies of potash. Most of the reduction plants have been erected in the neighborhood of San Diego, California. Two general processes have been tried, incineration and fermentation. In 1917 the production of potash from kelp amounted to 3575 tons, and in 1918 it did not exceed 9000 tons. The kelp is cut by seagoing dredges, acting like huge mowing machines, transported to land and dumped. It is said that it costs $1.10 to harvest and dump a ton of seaweed averaging only 1.5 per cent potash, or $85 per ton of potash brought to land. Under these conditions not much hope can be entertained for the permanent success of an industry that aims to yield potash as a main product by the incineration method.

But much more favorable is the outlook for plants like that of the Hercules Powder Company. That company needed acetone and other organic solvents, and worked out processes for getting them from the fermentation of seaweed. The outlay for apparatus was enormous, and the scale of operations is

immense, but as acetone, oils, esters, organic acids, algin, iodine, salt and potassium compounds are prepared in correspondingly large amounts, there is reason to view this as a permanent industry, and not one to cease with the coming of peace. With large technical staffs and expert sales organizations available, the outlook is favorable.

CONCLUSION

And thus we see how Germany's "vaunting ambition doth o'er leap itself" as truly in technical fields as in military and governmental affairs. She had the world buying potash from her mines, and a fleet of merchantmen carrying it to the uttermost parts of the earth. Her customers paid whatever price was demanded, and considered competition hopeless. Then came war, and long preparation for a short, intense campaign—like those waged under Bismarck's direction—gave her an instant advantage over peaceable nations who thought of war in terms of Sherman's definition. Conquest for booty, loot and subjugation of alien peoples—sordid and selfish motives all—was to the Junker and militarist only "big business."

But how she miscalculated the moral, mental and material reserves of an outraged world! Instead of having but one or two antagonists to dispose of at a time, the other nations being cowed into inaction through physical fear, she was soon surrounded by the dreaded wall of blood and iron, a circle of steel, and brought to bay, with a world against her. The eleventh hour of the fateful eleventh day of the eleventh month, 1918, marked the end of actual hostilities. What a reversal of form!

And what a shock it will be to the government-controlled Kalisyndikat to realize that its monopoly has been broken, that America increased its potash production from practically nothing in 1914 to 10,000 tons in 1916, 33,000 tons in 1917, and 65,000 tons in 1918, with the prospect of ever increasing production until all that is needed can come directly from local plants!

America's economic independence of German potash is thus a valuable by-product of this frightful World War, a result entirely unforeseen by friend and foe in 1914. The end has not

been reached without hard work, scientific skill, ample capital, constructive ability and business daring on the part of our citizens, but this victory in an art of peace is no less splendid than that won in war itself. Its story constitutes another chapter in the romance of American industrial achievement.

ADDENDUM

Revised statistics issued since the above was written give a somewhat smaller production of potash during 1918 than was estimated in October of that year. Press Bulletin No. 399 (February, 1919) of the United States Geological Survey reads in part as follows:

Statistics of the production of potash in the United States in 1918, which are complete except for reports from some of the smaller producers, show a large increase of output. The returns now at hand indicate a total production of 192,587 short tons of potash materials containing 52,135 short tons of actual potash (K_2O). They are summarized in the following tables, compiled by W. B. Hicks, of the United States Geological Survey, Department of the Interior.

Potash produced in the United States in 1918, classified according to sources

SOURCES	NUMBER OF PRODUCERS	TOTAL PRODUCTION	AVAILABLE POTASH (K_2O)
		tons	*tons*
Natural brines	21	147,125	39,255
Alunite	4	6,073	2,619
Dust from cement mills	9	11,739	1,429
Kelp	6	14,456	4,292
Molasses distillery waste	4	9,505	3,322
Steffens waste water	5	2,818	761
Wood ashes	26	609	365
Other sources	3	262	92
Total	78	192,587	52,135

The production in 1918 was almost double that in 1917. About 75 per cent of the total output came from natural brines, 55 per cent coming from brines in Nebraska alone. Most of the product was in the form of mixed salts and fertilizer materials containing from 20 to 30

per cent of potash (K_2O). About 24 per cent of it was in the form of muriate and about 6 per cent in the form of sulphate.

For several years immediately before the European war the United States used annually an average of about 240,000 short tons of actual potash (K_2O). The production so far reported in 1918 is therefore about 22 per cent of our normal consumption. The imports during 1918 were very small. The producers reported that on January 1, 1919, they had in storage 60,426 tons of crude potash, held because of the dull market prevailing during the latter part of 1918. These figures represent a minimum, as some producers did not give quantities, but stated that they had produced considerably in excess of sales. Most of the potash now held in storage was produced when the price was high, when quantity production was the main object, and when competition with foreign potash was not considered. The price now offered for that material is apparently below the actual cost at which many firms produced it, consequently there is a crisis in the domestic potash industry. Many producing plants have already shut down, and others are marking time.

The producing capacity of American potash plants, classified according to sources of raw materials, is estimated roughly as follows:

Capacity of American potash plants

SOURCE	AVAILABLE POTASH (K_2O)
	tons
Natural brines	
Nebraska lakes	50,000
Other sources	28,000
Alunite	4,000
Dust from cement mills	3,500
Kelp	5,500
Molasses distillery waste	4,000
Steffens waste water	3,000
Wood ashes	1,000
Other sources	1,000
Total	100,000

This quantity corresponds to more than 40 per cent of our normal consumption and indicates what may be produced in the United States during 1919 provided the American producers are able to compete with foreign producers.

It is evident that plants extracting potash from kelp were among the first to shut down after the signing of the armistice, and that many contemplated enterprises were allowed to die. Offsetting these abandoned projects in part at least, it should be noted that plants for making potassium chloride and sulphate from leucite are now operating.

THE USE OF OUTLINE CHARTS IN TEACHING VERTEBRATE PALEONTOLOGY

MAURICE G. MEHL

It is undoubtedly the common experience of all teachers of vertebrate paleontology and comparative osteology that only those anatomical structures or relations presented to the student through visual instruction become a part of his real working store of knowledge. Occasionally the exceptional teacher is able to fix uninteresting facts in the student's mind by means of fitting illustrations, fascinating stories, or accounts of first hand experiences. Certain it is, however, that only in proportion as the student visualizes a structure is he able to retain it. For this reason the teacher of paleontology usually feels very keenly the need of a large supply of museum or laboratory materials; mounted skeletons, skeletal parts, drawings, charts, transparencies, etc.

There are few colleges or universities that have an adequate supply of skeletal material for teaching vertebrate paleontology to the best advantage. Even so, much of the material available is not entirely safe in the hands of the inexperienced student. As a rule the lack of space, the cost involved, or the fact that collections are built up but slowly and many specimens cannot be duplicated, holds the collections down to a few illustrative types. Each institution is inclined to specialize in, to over emphasize, perhaps, the group or groups which are most available to it, and for illustrative material in other groups the student is forced to depend on written or oral descriptions and drawings. Were one able to study in several institutions till the entire field had been covered this would constitute ideal instruction, to be sure, but this is impossible in many cases.

It was because of a lack of skeletal parts by means of which the student could become thoroughly acquainted with the struc-

tures illustrating the main types of vertebrates that the writer was led in an attempt to supply the materials by means of charts. It was recognized that even when certain structures were well described, such illustrations as were available were often inadequate and gave the student little more than an idea of the shape of the bones. Even to gain this it was usually necessary to work through a great mass of literature, often not available. To work out a chart for each form or group with which it was desired to become familiar would mean an endless task. Furthermore, such charts would not have the vital interest which the preparator gains as he "works out" and mounts a skeleton. It was thought that could the student be furnished with a set of conventional "paper bones" from which he could construct skeletons at will, much of the difficulty of teaching the vertebrate skeleton would be eliminated.

Some time ago the writer conceived the idea of compiling a guide chart on which were designated the elements in the primitive skull together with the conspicuous openings in their proper relations. Working on the principle that organic evolution involves only the loss of parts or the modification of existing elements, the student was expected to construct any skull from the base by discarding or utilizing the lines bounding the primitive elements.

The results of this experiment were very gratifying. While the guide chart had been compiled for the sole purpose of supplying laboratory materials, it was found that it answered other purposes as well. In the first place the student came to realize that it was the elements and openings and their relations in the skull that were all important; the size and shape were of secondary consideration. The use of the same size and shape of skull to show the structure of various types seemed to give a new meaning to the word "structure": the student observed that between the largest and the smallest dinosaur skulls there were fewer differences than between many skulls that in a hasty glance seemed very similar.

Again, he came to a realization, as never before, that every form, no matter how complicated, was merely a modification,

through loss chiefly, of a pre-existing, more generalized type, a fact strikingly presented by the discarded parts that accompany every "finished" skull.

Not least of the advantages of the guide charts was the manner in which they assisted the student to become familiar with the technical terms. After he has worked out several types and labeled each element, every name comes to have a rather definite meaning.

Encouraged with the results gained from the use of the chart for the skull and at the suggestion of the late Dr. S. W. Williston, the writer attempted the compilation of guide charts for the limbs and the vertebrae. These guide charts, together with some suggestions as to their use are presented herewith.

THE SKULL

The chart for the skull, plate IX, consists of dorsal, ventral, and posterior views. It is accompanied by a form suitable for student use in the laboratory. While the chart was designed primarily to illustrate the amphibians and reptiles, it may be used for the mammals and birds. The solid lines mark the outlines of the skull and the openings commonly present such as the orbits and nares. It is only in exceptional cases, for instance, to close the otic notch, that these lines should be modified.

In the dorsal view the elements found in the primitive skull are outlined by dots. Each bone in the type to be represented should be designated by following its dotted outlines with heavy, preferably red, lines. When an element or elements are missing, the outlines are ignored and the adjacent bones are expanded in the proper directions to fill the space and maintain the proper relations. In the exclusion of the lacrimal from the nares and in other rare instances, the dotted lines will necessarily be changed slightly.

In the ventral view the same plan is followed as in the dorsal. The dotted lines give a choice between a single and a double occipital condyle. A large and small interpterygoid vacuity are designated by dashed outlines and a dotted line from the

anterior end of each gives a choice between a large and small parasphenoid. It will be found that with the use of the small vacuity and small parasphenoid, the sutures between the palatines, pterygoids, and vomers will have to be slightly modified.

A false palate may be indicated by adding a line drawn across the bones of the palate along points at which the fold takes place. Arrows pointing from this line to the median line of the skull indicate the fold somewhat more effectively.

Teeth on the various elements may be designated by circles or crosses. The various types, thecodont, acrodont, etc., may be designated by special symbols agreed upon.

The posterior view gives a choice between a single and double occipital condyle. When the single condyle is utilized the outline remains unchanged. The suture between the tabular and the paroccipital is left incomplete so that it may be continued toward the median line of the skull in any direction so as to maintain the desired relations between the supraoccipital and the laterally adjacent bones.

An index sheet, plate VIII, furnishes the names in common use for the various bones of the skull. Most of the openings are indicated in a like manner. To eliminate confusion, openings are indicated by a curved line beneath the abbreviation for the name. Unpaired bones are underscored with a straight line. In filling out a chart the same abbreviations should be used as are given in the index sheet, and the openings and unpaired bones should be designated in the same manner.

THE LIMBS

The guide chart for the limbs, plate X, furnishes outlines for both the front and the hind legs. Names of the various elements should be added by the student. All of the elements in the primitive leg are represented by conventional designs save in the case of the mesopodials. Here there is so much doubt as to the primitive arrangement and number, and such a variation among known forms, that only the lines to designate the three rows are given. Between these, vertical lines may be drawn to

indicate the number and relative proportions of the bones in each row. The loss of all or a part of the ulna or fibula may be shown by ignoring the outlines of these bones or by using only

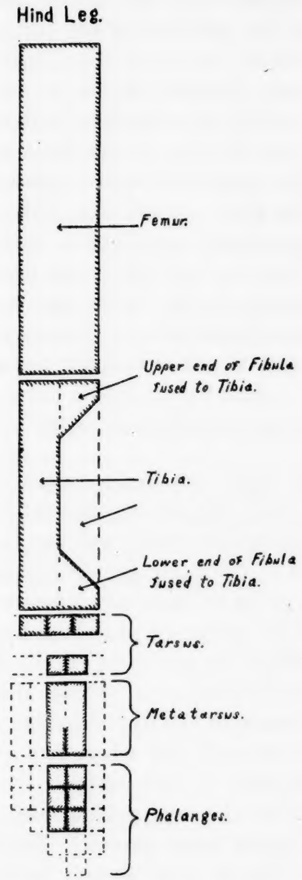


FIG. 1

those lines bounding the part retained. The fusion of two bones is indicated by omitting the division between them. In the humerus the presence of the ectepicondylar or entepicondylar

foramen is indicated by following the dotted circles near the distal end of this bone. These foramina may be further emphasized by placing a cross within the circle. A hyperphalangeate or hyperdactylate condition in the hand or foot may be indicated either by the addition of new squares or the splitting of the present rectangles by vertical or horizontal lines or both.

The accompanying diagram, figure 1, shows how the completed chart for a purely hypothetical form might appear. The features indicated are the loss of the shaft portion of the fibula and the fusion of the upper and lower ends of this bone with the tibia; the loss of the first, second, and fifth metatarsals and the partial fusion of the third and fourth; and the loss of all the phalanges in the first, second, and fifth fingers and the loss of one and two phalanges in the third and fourth fingers respectively. In the tarsus there are but two rows of bones with three elements in the proximal and two in the distal row.

THE VERTEBRAE

While the guide chart for the composition and modification of the vertebrae, plate XI, is not all that could be desired for certain primitive forms, it works well for the great majority of types. The names of the parts should be added by the student.

In the end view given in this chart a perforate or solid centrum may be shown. The upper set of dotted angles near the neural canal is used to show the presence of the zygosphene and the lower set is for the hyposphene. While the lateral view shows the presence or absence of the hypocentrum and its relative size, it is also shown in the end view where it may be designated as a single unit or composed of two parts.

In the lateral view the composition and modification of the centrum may be more fully shown. Temnospondylous types as illustrated by *Cricotus* and *Eryops* may be shown by utilizing certain of the dotted lines while holospondylous forms are indicated by ignoring these. The presence of an intercentrum is indicated by following another dotted line that cuts off a small triangular space in the lower anterior corner of the out-

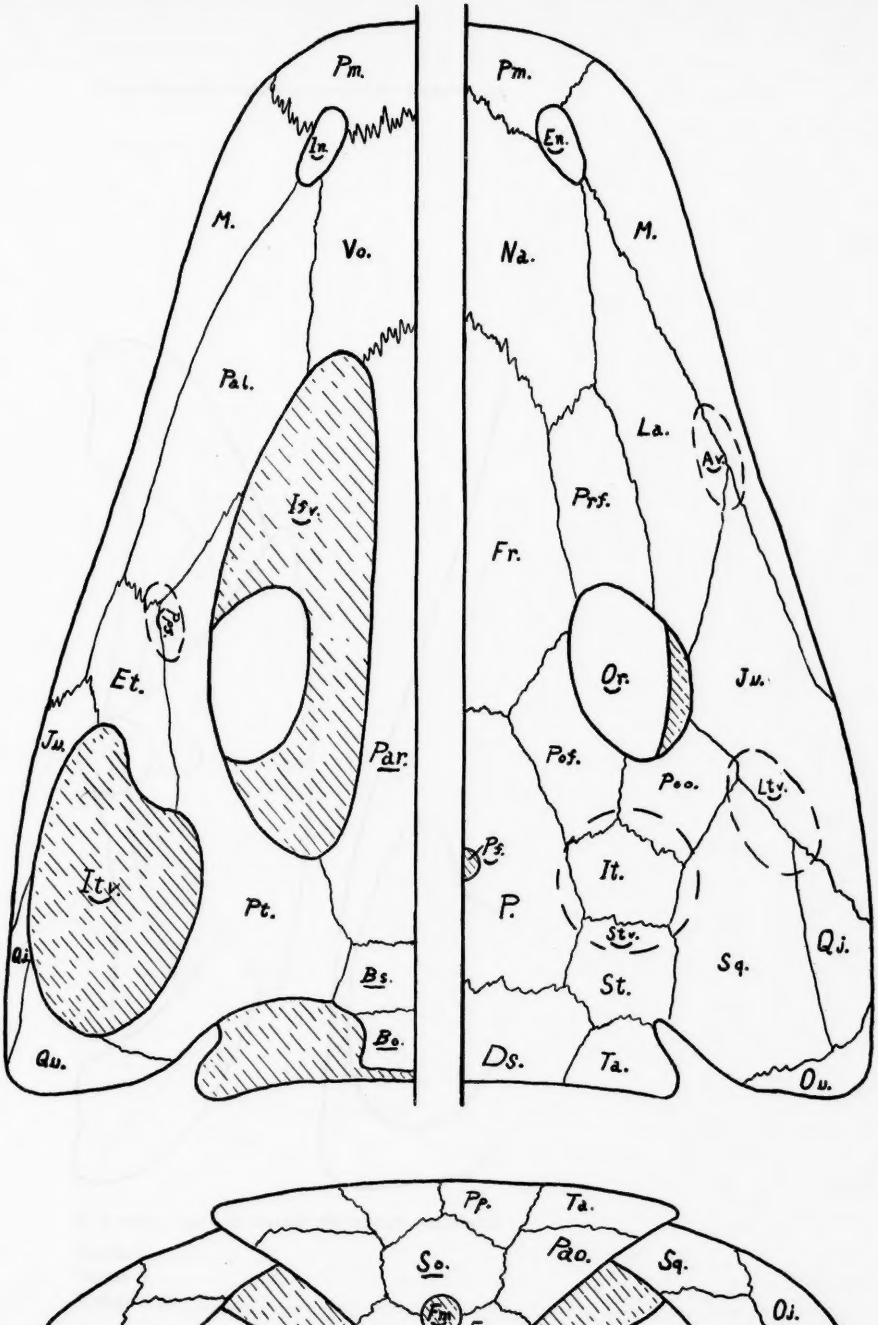
line of the centrum. For amphiplatyan vertebrae the lines at the ends of the centrum are not altered, but for procoelous, opisthocoelous, and amphicoelous types the suitable curved dotted lines are to be used. It has been found useful to outline the several elements composing the vertebrae with hachures as is shown in the illustration of foot structure (fig. 1).

The importance of the rib articulation has long been recognized. No two animals with different rib articulations can be closely related. For this reason the facets on the vertebrae should be carefully noted. In the lateral view of the vertebra the small dotted circles permit the designation of all possible rib attachments. For a double, diapophysial attachment a cross should be placed in each of the two circles on the diapophysis. Obviously the small half circles at the posterior end of the centrum are used to indicate intervertebral attachments.

No doubt the guide charts as here presented are inadequate in many respects and not unlikely will they be found to contain certain errors. Other uses of the charts may suggest themselves and perhaps other forms may be added. The writer has tried forms for showing the structure of the pectoral and pelvic girdles and also a form for showing the evolution of the teeth. In both of these cases, however, the results were of doubtful benefit because of the complexity of the charts.

PLATE VIII

Av, antorbital vacuity
Bo, basioccipital
Bs, basisphenoid
En, external nares
Eo, exoccipital
Et, ectopterygoid (transverse)
Ds, dermosupraoccipital (postparietal)
Fm, foramen magnum
Fr, frontal
In, internal nares
Ipv, interpterygoid vacuity
It, intertemporal
Itv, intertemporal vacuity
Ju, jugal
La, lacrimal
Ltv, lateral temporal fenestra
M, maxilla
Na, nasal
Or, orbit
P, parietal
Pal, palatine
Pao, paroccipital (opisthotic
Par, parasphenoid
Pf, parietal foramen
Pm, premaxilla
Po', postfrontal
Poo, postorbital
Ppf, postpalatine foramen
Prf, prefrontal
Pt, pterygoid
Qj, quadratojugal
Qu, quadrate
So, supraoccipital
Sq, squamosal
St, supratemporal
Stv, supratemporal vacuity
Ta, tabular
Vo, vomer
◡ an opening
— an unpaired bone


Pm.
In.
M.
Vo.
Pal.
Isv.
Et.
Ju.
Par.
Itv.
Pt.
Qj.
Bs.
Bo.
Qu.
Pm.
En.
Na.
M.
La.
Av.
Prf.
Fr.
Or.
Ju.
Pof.
Poo.
Ltv.
Ps.
It.
P.
Stv.
Sq.
Qj.
St.
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Ta.
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Ta.
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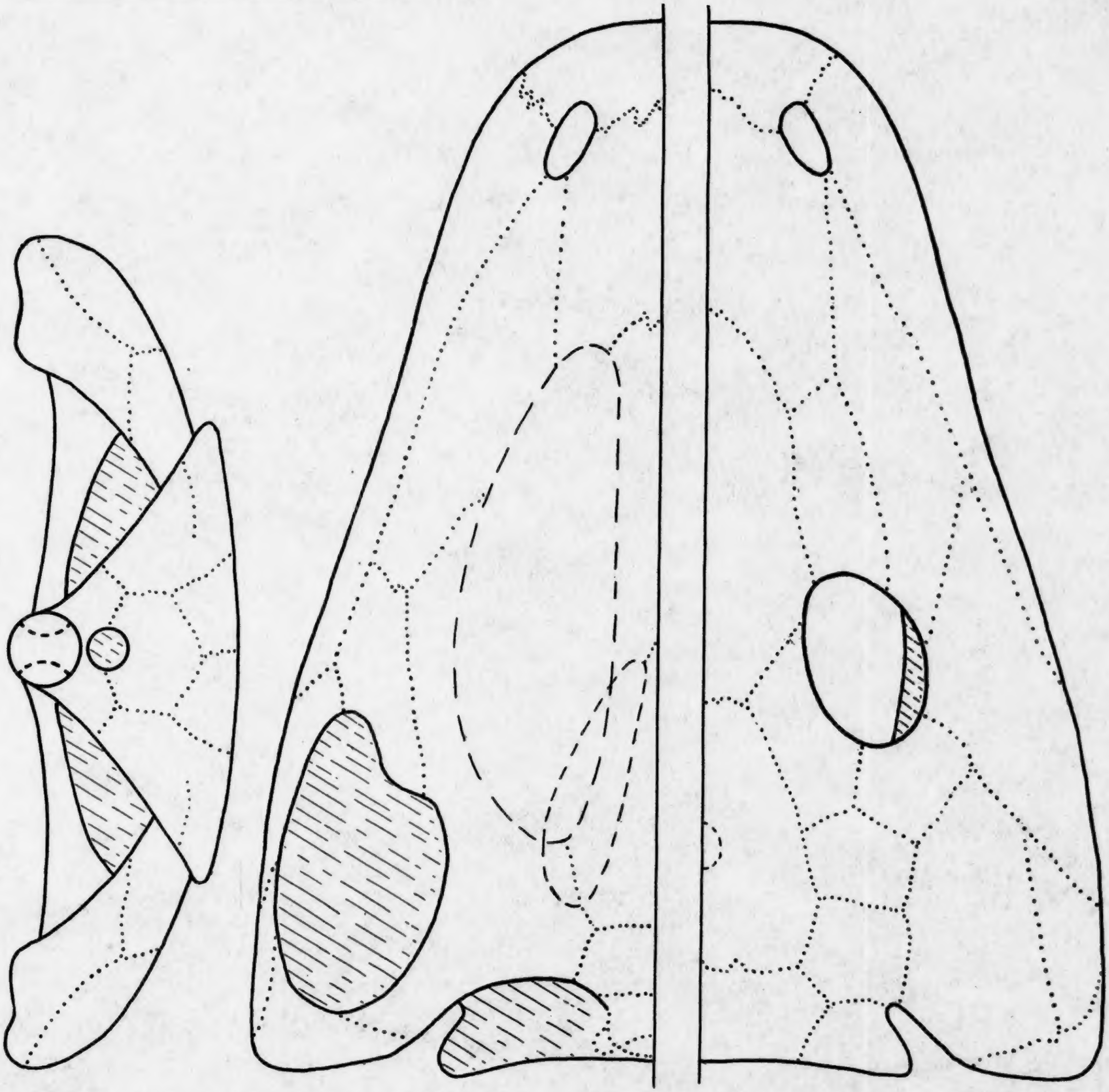
Qu.
Bo



M. G. MEHL: OUTLINE CHARTS VERTEBRATE PALEONTOLOGY THE SKULL

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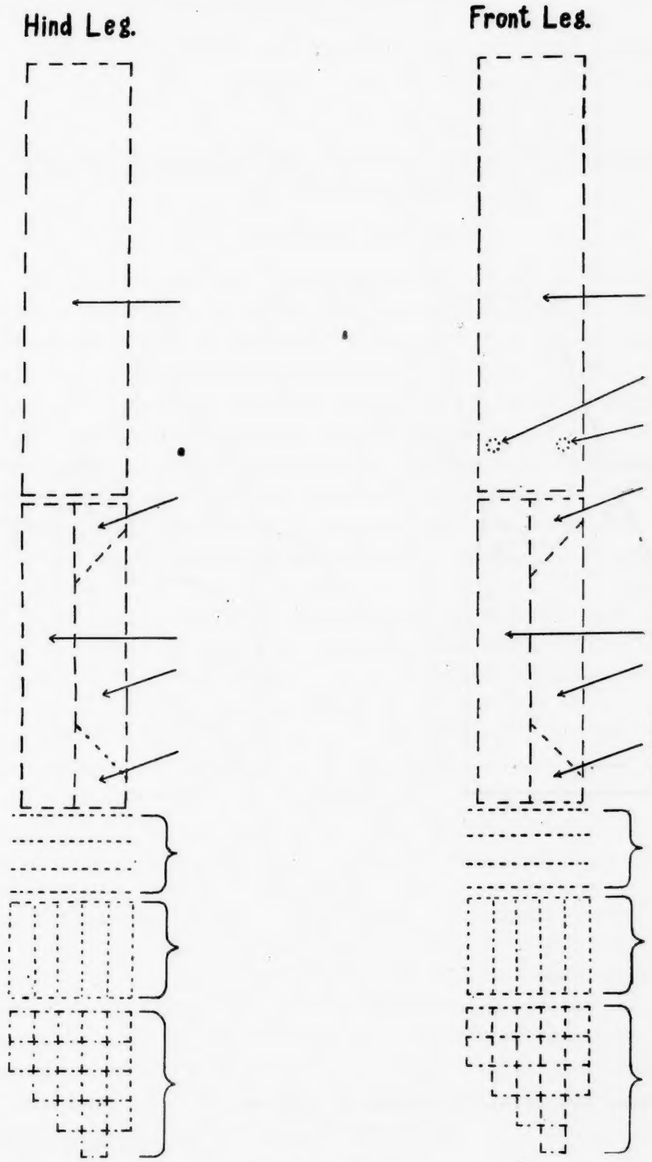

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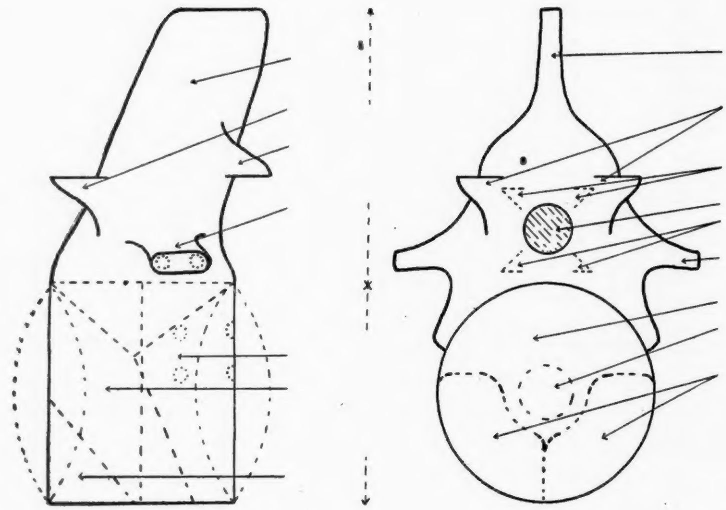


M. G. MEHL: OUTLINE CHARTS VERTEBRATE PALEONTOLOGY. THE VERTEBRAE

SOME FACTORS IN THE GEOGRAPHIC DISTRIBUTION OF PETROLEUM

MAURICE G. MEHL

Few industries have experienced such rapid or so comprehensive development as has the petroleum industry. The use of petroleum and its products is so firmly fixed in the affairs of man and so important are these products to his activities of industry and pleasure that even a slight reduction in the petroleum output would probably work real hardships on a large proportion of the human race. The discovery of new areas of accumulation of petroleum and the rapid development of these new fields have followed each other in rapid succession during the past few years. Production, nevertheless, scarcely keeps pace with the growing demands.

Some look with alarm on the rate of consumption of our known supply of petroleum and many are already studying the possibilities of new stores from other sources or other regions. Not a few of the larger corporations are sending representatives from time to time to investigate the possibilities in unexplored or inadequately tested parts of the world.

Whether an actual shortage faces us at some near date or not, certain it is that at some future time it will be necessary, or at least desirable, to determine what may be expected in the way of a world supply of petroleum. When prospecting is carried into regions of unknown possibilities, to countries not now important as producers of petroleum, what is to be the guide; what shall determine the order in which the various "possible" regions are to be investigated? Just as today experts are able to designate the most favorable places for testing a given region, will it not be possible in the future to indicate, within the confines of well founded theory, at least, a logical order in which the land masses of the earth should be tested?

In the following paragraphs the writer attempts to correlate certain facts and observations which may assist in the solution of some of the problems in the geographic distribution of petroleum. There is no attempt at exhaustive treatment and little or no claim is made for originality. It is hoped that the speculations will call forth a discussion of the principles involved and possibly stimulate investigations in the several branches of science interested. It is only through the coöperation of the experts in these sciences that adequately supported conclusions as to the likely distribution of petroleum can be reached.

Considering petroleum and the related substances as a group, they are among the most widely distributed minerals; there are but few unmetamorphosed sedimentary beds that contain no trace of these hydrocarbons. Small showings are found encircling the globe and they extend from well toward the poles to the equator. Workable accumulations are much less widely distributed, however, and great commercial deposits are comparatively rare.

On the accompanying map, plate XII, are platted the more important areas of production throughout the world. It will be noted at once that these major accumulations, as they may be termed, are confined to the northern hemisphere. It will also be seen that none of the areas indicated extend north of 50° N. latitude nor south of 20° N. latitude. In fact, if one is to avoid extremely sinuous lines, perhaps no better boundary could be desired than these parallels.

True, outside of this belt are known deposits of some magnitude, accumulations that might be classed with the major fields, such, for example, as those of Alaska, Peru, or Ecuador. These and other possible exceptions, however, are in no wise comparable with the productive areas about the Black and Caspian Seas, the Lorraine district, the great belt across the United States, or the accumulations in Mexico.

Attention is further called to the general correspondence between the position of the twentieth and fiftieth parallels in both hemispheres with the average annual isotherms of 70° and 40° respectively. Although these parallels are, in reality, nothing

more than imaginary lines of geographic reference, each does, in much probability, mark the average position of some isotherm as it has shifted in past geological times. While the disposition of maximum accumulations as here bounded does not indicate a definite temperature zone within which petroleum has been formed, it does suggest a distinctly zonal distribution of petroleum in which temperature may have been an important factor.

At once the question arises as to whether these apparent boundaries of the zone of maximum accumulations fit well with the actual conditions or whether further investigation will greatly modify the shape and extent of the "important" areas. If there is this actual zonal distribution of petroleum, one must consider several factors involved in such limitation and with these speculations others follow such as the possibility of a "barren" equatorial belt and a productive zone in the southern hemisphere corresponding with that of the northern.

There is, of course, grave danger in assuming that the belt of maximum production is as observed, or that such an area may be expected to have anything in the way of a definite boundary, even theoretically. There can be little doubt, for instance, that this zone has offered the most favorable conditions for exploration and it is not unlikely that with more extensive prospecting other great accumulations of petroleum will be found, possibly well outside these approximate boundaries.

Regardless of the lack of thorough prospecting, however, there is reason to believe that of the three zones, the equatorial belt between the twentieth parallels and adjacent belts in the northern and southern hemispheres extendingn orth and south to the fiftieth parallels, the northern belt will, when investigations are carried to completion, be found the more productive. For instance, one may safely assert that, all other factors being equal, the amount of petroleum underlying a given area is directly proportional to the size of that area. It is evident that in the area of exposed lands neither the southern nor the equatorial belts compare favorably with the northern zone.

Inasmuch as important accumulations of petroleum in Pre-Cambrian rocks are unknown, certain broad areas of Pre-Cam-

brian and igneous rocks may at once be designated as impossible territory. The proportion of the possible productive territory to the total area in each zone differs greatly. Again the differences favor the northern zone for the proportion of the Post-Cambrian area to the total land surface is much greater in this belt (see plate XIII). Furthermore, the "possible" territory in the other zones includes considerable areas that may properly be eliminated because of the presence of sediments representing periods that are generally barren throughout the world, such as the broad expanse of supposed Triassic rocks in northeastern South America and the great areas of Mesozoics in eastern Australia and central Africa.

The foregoing considerations are all, in a sense, passive agents, factors which would tend to minimize the importance of petroleum accumulations outside of the northern belt. So closely confined to this belt are the great accumulations as they are known today that it is thought there must be a more active determining factor; one of the fundamental influences in the formation of petroleum. Of these, one of the most far reaching is probably the temperature consideration.

It may safely be granted, perhaps, that petroleum is derived from organic matter. Without going into the evidence it may also be stated that there is reason for assuming that no particular group or groups of organisms may be designated as the source of petroleum except that all evidence points to the fact that it is only the smaller plants and animals, perhaps largely the microscopic forms, and fragmental material from larger organisms that are available.

It is evident that there is a marked dependence of life on temperature conditions. Perhaps this one factor, more than any other, determines the variety and abundance of life throughout the world. It is recognized that the amount of agitation of the waters, the degree of salinity, the nature and amount of sediment, the depth of the water, etc., are very important factors in the distribution of marine life, but for every temperature these other conditions may be found in almost endless variety and combination. Still, life is not equally abundant in every

temperature. While it is true that there is more or less of a "patchwork" arrangement of temperatures in the ocean, cold waters often immediately adjacent to warm waters, it may be said in general that the temperature increases toward the equator. Likewise, with conspicuous exceptions, the abundance and variety of life increases rapidly toward the equator. So far as the abundance of life alone is concerned, it seems likely that there has been some limit, poleward from which the formation of petroleum has been of little importance.

Other factors concerned in the origin of petroleum from organisms have been suggested, factors of equal or greater importance than the relative amount of organic matter available. Two of the most conspicuous of these is the rate of decay of organic matter and the rate of sedimentation. A brief consideration of some of the principles involved will make the importance of these factors more evident.

Many sorts of organisms have been subjected to destructive distillation in an attempt to produce petroleum. Of these substances a large number, both plant and animal and various combinations, have produced oils very similar to natural petroleum. It has been noted in all cases, however, that it is the fatty portion of the organism that produces the desired results. In every case where the entire organism is utilized the simulation of petroleum is much less marked, especially in the presence of large proportions of nitrogenous bases in the synthetic product. Apparently in nature there has been a very efficient denitrifying agent coöperating in the formation of petroleum.

As such a denitrifying agent, nothing more adequate, more logical is suggested than denitrifying bacteria. While the abundance, the importance, and the exact rôle of these organisms is not generally understood, the principles involved are evident. Apparently their first activity in the destruction of organic matter is the consumption of the nitrogenous portions; the fatty parts are for a time untouched. In the decay of a given amount of organic detritus, up to a certain time, there is an actual increase in the proportion of fatty material to the whole.

The destruction of organic matter by denitrifying bacteria is not confined to the nitrogenous portions alone, however; in time the fats are also attacked and, in the normal process of decay, these too are entirely destroyed. Obviously, other factors being equal, in those regions in which denitrifying bacteria are most active the destruction of the fatty portions of organisms should be fastest and most complete; there should be the least likelihood of the formation of petroleum. For ideal conditions in the formation of petroleum the denitrifying bacteria should be sufficiently active to denitrify the organic base, but their abundance should not make possible the excessive destruction of the fatty portions.

Vaughan has pointed out the part played by denitrifying bacteria in the precipitation of calcium carbonate from sea water and has stated that this activity, if not confined to tropical waters, is at least most marked in the warmer portions of the sea.[1] Drew, in speaking of *Bacterium calcis* and other denitrifying bacteria, says:[2]

> Such action would be almost limited to comparatively shallow seas whose temperature approximated to that of tropical seas at the present time.

Now, while such investigations offer no conclusive evidence as to whether denitrifying bacteria are sufficiently active to effectively destroy the fatty portions of decaying organic matter in the equatorial belt, they do indicate that the destruction would be progressively greater toward the equator, other factors being equal. From this standpoint it does not seem unlikely that throughout past times there have been fluctuating boundaries beyond which, toward the equator, conditions for the formation of petroleum have been subnormal.

[1] Vaughan, T. W., Preliminary remarks on the Bahamas, with special reference to the origin of the Bahaman and Floridian oolite: Carnegie Inst. Washington, Pub. no. 182, pp. 47–54, 1914.

[2] Drew, G. H., On the precipitation of calcium carbonate in the sea by marine bacteria, and on the action of denitrifying bacteria in tropical and temperate seas: Carnegie Inst. Washington, Pub. no. 182, pp. 7–45, 1914.

While the importance of the temperature check on the activities of denitrifying bacteria has been indicated, it is obvious that there must be a check of another sort as well. In any region where the bacteria are sufficiently active to denitrify the organic base of petroleum more or less completely, the fats would also be destroyed were such a check not operative.

It has been assumed by some writers that the formation of petroleum would in itself constitute an automatic check on bacterial destruction by virtue of antiseptic products. This is not in keeping with the observed processes of decay, however, and it assumes, furthermore, that petroleum is formed almost, if not quite, as rapidly as the nitrogenous bases are destroyed. As a matter of fact, all evidence points to an opposite condition, the extreme slowness with which petroleum is formed. It is, perhaps, not far from correct to assume that the hydrocarbon substance in oil shales is the somewhat altered organic base which, after the lapse of an extremely great length of time, has not yet been transformed into the ultimate product, petroleum. It is only by hastening the process through destructive distillation that petroleum may be derived from these shales.

There is, apparently, a check of a mechanical nature found in the accumulation of inorganic sediments. It is generally recognized that accumulations of soil and fine sediment materially limit the activities of bacteria. It follows that the more rapid the deposition of fine sediments, the more complete the check. In much probability the fineness of the sediments has been one of the most important of the factors determining the rock associations of petroleum. At any rate, petroleum is associated primarily with shales. The presence of nitrogen in varying proportions in petroleum would seem to testify to the effectiveness of the shales as a check on the destruction of organic matter on occasion. In the cases of marked proportions of nitrogen we may suppose, perhaps, that not only have the fatty portions of the original base been protected, but that not even all of the nitrogenous parts have been destroyed by bacterial activities.

It may be assumed that in general the rate of sedimentation is slower in the equatorial belt than elsewhere, a fact evidenced

by the thick accumulations of soil on these lands. Again, from the standpoint of the inadequacy of the check on the destruction of the fatty base by bacteria, the equatorial belt should be less favored in accumulations of petroleum. This too is largely a function of temperature, for the slow rate of sedimentation is in no small measure due to the luxuriant growth of vegetation which prevents the free wash of the rock waste from the land.

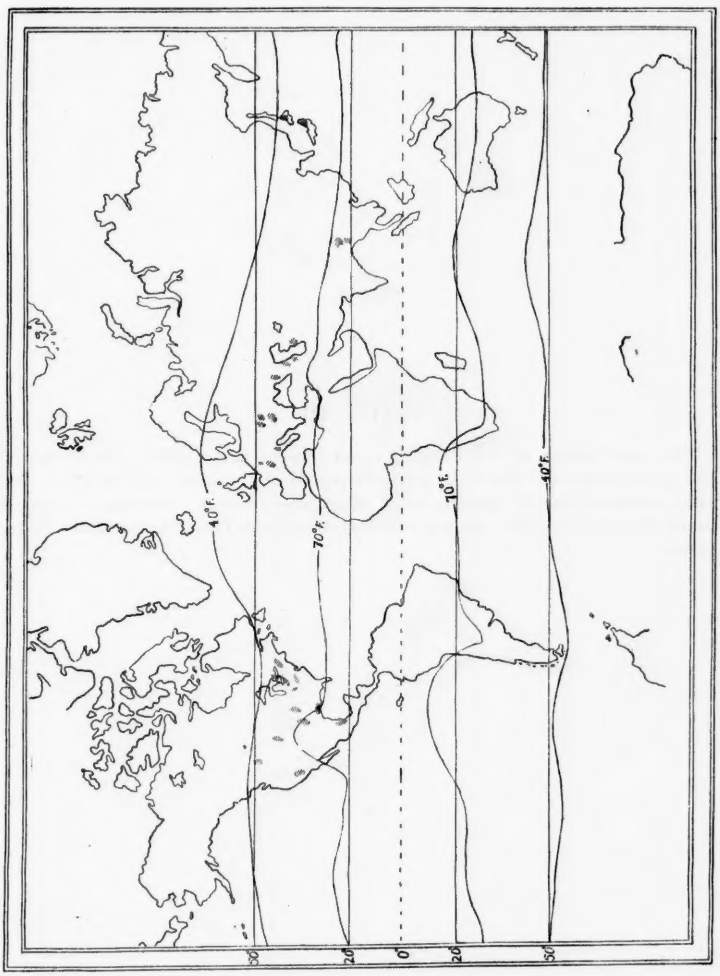
Aside from its function as a check to the activities of denitrifying bacteria, the rate of accumulation of inorganic sediments is of further importance in the formation of petroleum. Very often the rapid decay of organisms is pointed to as illustrating the manner in which petroleum is formed. In certain parts of the Mediterranean Sea, for instance, the accumulation and decay of organic detritus is so rapid that the lower levels of the water are filled with scattered globules of oil. Instead of illustrating how petroleum is formed, however, it points to the effective manner in which fatty matter is ordinarily separated out from accumulating sediments. Certainly, the globules of oil which are escaping into the water offer no suggestion of being retrapped and converted into petroleum. It is only that part of the organic matter which is converted into oil so slowly that the accumulating sediments form a sufficient thickness and suitable succession to retain it against the tendency of the associated waters to drive it off, that may become petroleum.

If we may grant, then, that within a limited zone, the equatorial belt, conditions have been unfavorable for the formation of accumulations of petroleum, on the average, it is logical to seek a belt in the southern hemisphere suitable for such deposits, to correspond with the belt in the northern hemisphere. Were the temperature factors alone to be considered, there is little doubt but that much might be expected from the southern zone. It has already been pointed out, however, that the area of exposed land within this zone is relatively small and of this a very large proportion consists of Pre-Cambrian or igneous rocks. Apparently little more is to be expected from the southern belt than from the equatorial zone.

Now, while in the foregoing paragraphs certain considerations have been presented which point to the maximum petroleum accumulations in a zone between the twentieth and fiftieth parallels in the northern hemisphere, it would be a grave error to assume that nothing is to be gained by prospecting outside of this belt. Even if later investigations should show the speculations here presented to be well founded, it would seem in keeping with the theories advanced that there should occasionally be found within the very heart of the equatorial belt, accumulations of importance. As a working hypothesis only, it is suggested that the prospector's efforts will much more likely be rewarded in the northern than in the southern belt and that he is least likely to achieve the desired results in the equatorial zone.

PLATE XII

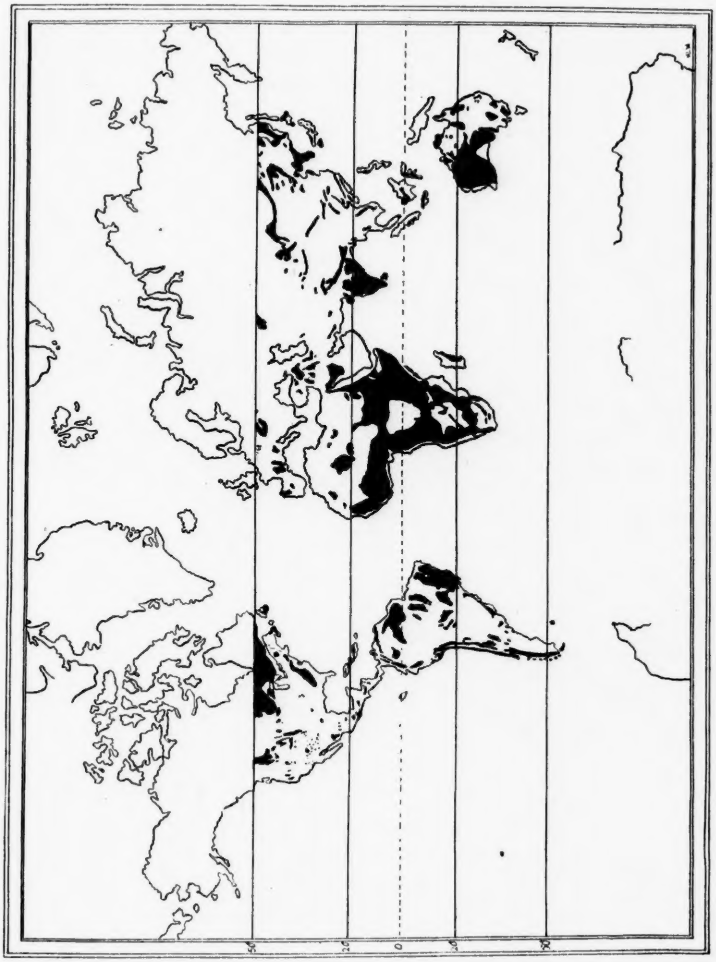
The geographic distribution of petroleum. The known accumulations of petroleum of major importance are indicated by oblique lines. The size of many of the areas is greatly exaggerated and the locations are only approximate.



M. G. MEHL: GEOGRAPHIC DISTRIBUTION OF PETROLEUM

PLATE XIII

The distribution of Pre-Cambrian and igneous rocks within the equatorial and adjacent belts. The black portions represent the chief areas of Pre-Cambrian sedimentaries or igneous rocks of any age. Areas concerning which no information is available are not differentiated from Post-Proterozoic sedimentaries.



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